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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Part I

on

The Disorientation Incident

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.95

PART I

THE DISORIENTATION INCIDENT

Edited by

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Papers presented at the Aerospace Medical Panel Specialist
Meeting held in Luchon, France, 28 September 1971

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The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

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FOREWORD

It is the exchange of information which is one of the fundamental missions of AGARD, and towards which our Annual Meeting of the Aerospace Medical Panel is specifically directed.

In this instance we have, through the hospitality of the French National Delegates, had the opportunity of holding our Autumn Meeting of 1971 in Luchon in the Pyrénees. One of the advantages of a meeting in a small town is that the delegates are kept in close touch with one another, which makes the exchange of information on an unprogrammed basis even more effective.

The programme itself, with its three themes: disorientation, simplified methods for clinical examination of aircrew, and biophysical problems in aerospace medicine, reflects the wide range of expertise available in our Panel - an expertise which is directed towards the problems of the operators in both the military and the civil environments, since the same type of problem is frequently encountered in the two fields.

The quality of the presentations was commented upon most favourably, and I would like to take this opportunity of thanking the authors on behalf of the Panel. I wish also to thank the editors of the Technical Evaluations, which provide an expert review of each phase of the meeting, so that the salient points and broad conclusions reached in discussion may be permanently recorded.

Group Captain T C D Whiteside, RAF
Chairman ASMP

PREFACE

One of the principle objectives of AGARD is to promote the exchange of scientific and technical information within the NATO countries. The pages which follow are a permanent record of the proceedings of a meeting, organised by the Aerospace Medical Panel of AGARD, which was devoted to the problem of spatial disorientation. The limitations of mans' ability to sense aircraft attitude and motion are one of the main causes of the sensory illusions embraced by the term 'disorientation in flight'. These have been recognised for over fifty years and are well described in aeromedical text books. However, the operational consequences of spatial disorientation, in particular the loss of life and aircraft in orientation-error accidents and the ways in which disorientation may be ameliorated, are less clearly understood. The papers presented at the 28th Meeting of the Aerospace Medical Panel make good this deficiency and provide a convenient digest of current opinion and research into the more practical aspects of the problem of spatial disorientation in flight. It is considered that these Proceedings will be of value, not only to aeromedical specialists, but also to those engaged in the training of aircrew and in operational duties.

The value of published proceedings is enhanced by the inclusion of the informal exchange between participants, for such discussion underlines important findings or exposes weaknesses in argument and technique. It is an important part of the editor's task to produce an intelligible text of such discussion from recorded commentary and from forms which participants were asked to complete. In my limited experience, only about a third of the actual discussion is reflected in these 'discussion forms' and the editor must rely heavily upon the tape recording if an accurate account is to appear in the printed proceedings. On this occasion my task was made the more difficult because only about 40% of the discussion was recorded due to an intermittent fault which was not discovered until some time after the meeting. For a few papers the recorded discussion was complete, but for the others I have had to rely on written comments and hazy recollection, so the discussion as printed is incomplete. This deficiency is much regretted. To those authors and speakers who are not adequately represented I extend the apologies of the recording engineers. To those who are misrepresented, I alone bear responsibility.

A J BENSON
Technical Programme Organiser
and Editor

SUMMARY

This volume contains the text of 16 papers, related to the problem of spatial disorientation in flight, which were presented during the first part of the 28th Meeting of the Aerospace Medical Panel, held at Luchon, France, 28-30 September 1971. The papers covered the following topics: 1. description and analysis of disorientation incidents, 2. orientation error accidents, 3. training procedures, 4. laboratory studies. The principal findings and recommendations are summarised in a Technical Evaluation Report.

OPENING CEREMONY

The civil and military dignitaries who took part in the opening ceremony of the 20th Meeting of the AGARD Aerospace Medical Panel were introduced by the Chairman of the Panel, Group Captain T C D Whiteside.

The Co-ordinator for the host country, Médecin Général R Grandpierre, extended greetings to delegates and distinguished guests, in particular to the Director General of Medical Services of the French Armed Forces, Médecin Général P G Lenoir, and to the Mayor of Luchon, Dr A Castaigne. On behalf of the French National Delegate, Général Grandpierre expressed pleasure that the 20th Meeting of the Aerospace Medical Panel was being held in France. He emphasised the importance which the National Delegates attach to the exchange of information within the NATO countries and in particular their aspirations for the success of the meeting in Luchon. He had no doubt that this objective would be fulfilled since the civil authorities of Luchon, had, by their generous hospitality provided a most favourable milieu for a meeting which had attracted contributions of a high technical standard.

Général Lenoir in his address, expressed appreciation to Général Grandpierre and to the Chairman of the Aerospace Medical Panel for inviting him to attend the opening ceremony and for the welcome which he had received since his arrival in Luchon.

Général Lenoir said that his interest in AGARD and in particular the work of ASMP was two fold. As an army man, in charge of the combined Medical Services of the French Armed Forces, it was important that the found out more about the activities of Specialists in the field of Aviation Medicine. The other reason for his presence in Luchon, Général Lenoir explained, was more personal and stemmed from a meeting with the Chairman of ASMP. He was deeply impressed with the sincerity with which Group Captain Whiteside had explained to him the objectives of AGARD and the activities of the Panel he represented. The General was pleased to have the opportunity to express publicly his gratitude to the Chairman of ASMP for his work in promoting international co-operation.

Général Lenoir recognised the complexity of the aeromedical problems posed by modern military aviation and considered that as the operational requirements become more exacting, it was essential that there should be close co-operation in research and development in the discipline of aerospace medicine. The success of such international co-operation was dependant upon mutual trust and an attitude of 'fair play'.

In concluding Général Lenoir, reaffirmed the welcome to the delegates from the NATO countries who had assembled in Luchon and wished them every success in the technical sessions which would follow.

CONTENTS

DISORIENTATION INCIDENTS REPORTED BY MILITARY PILOTS ACROSS 14 YEARS OF FLIGHT*

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SUMMARY

Recent incidents involving disorientation in flight reported by 336 U. S. Air Force, Army, and Navy pilots were compared with incidents reported by 137 pilots in 1956. The incidents were strikingly similar for various types of aircraft and even for combat and noncombat situations. These findings and those of other investigators suggest that disorientation is currently experienced in a wide variety of flight operations throughout the world and will continue to be experienced by military aircraft pilots.

INTRODUCTION

The pilot's task in orientation to the horizon and to gravitational and gravitoinertial force has been one of the constant problems in aerospace medicine. Indeed, volume I (1930) of *Aerospace Medicine* (then the *Journal of Aviation Medicine*) reported on "Blind Flying," a symposium about orientation and disorientation in flight.[1] Since then many papers have been written on the topic, but no attempt will be made here to review this literature since it has been done recently by several others.[2-5] It is worth noting, however, that while materiel failure as a cause of aircraft accidents has decreased during the past decade, the relative importance of "pilot error" as a cause has increased.[6] Consequently, factors important in causing disorientation in flight also become increasingly important.

Disorientation is used in this discussion simply to refer to situations in flight in which the pilot's perception of the attitude, position, or motion of his aircraft or other objects in space is nonveridical (i.e., perception differs from physical events). Thus, disorientation encompasses a wide variety of perceptions that may deviate only slightly from veridicality, or may result in gross perceptual errors leading to inappropriate control movements or to accidents. Hixson, Niven, and Spezia[7] have defined such "orientation-error accidents' as those "... said to occur whenever an accident results from a pilot's incorrect perception of his true motion and attitude in space."

Disorientation of one type or another is ubiquitous in military flight operations.[1,7-9] Recent reports have described disorientation in many different aircraft and many countries, e.g., Canada,[10] Czechoslovakia,[11] Japan,[9,12] Russia,[2,5] the United Kingdom,[3] and the United States.[8,13,14] Consequently, there is a continuing interest in the topic, and many investigations have been undertaken to understand the many, complex factors that contribute to orientation and disorientation. Of these studies, a significant number have involved the vestibular system, which contributes in important ways to disorientation in flight, because of its special characteristics during the passive rotation of the pilot during flight.[3-5]

In spite of the increase in knowledge of the topic in the past 40 years, however, reports of disorientation experienced by pilots continue, sometimes as critical incidents and sometimes involving accidents.[7,9,11-13,16] This is not surprising because both orientation and disorientation are a result of complex perceptual systems interacting in complex ways.[2-4,15] Furthermore, extrapolation from the laboratory to flight with its own unique, complex environment must be undertaken with caution. Consequently, periodic investigations of critical incidents involving disorientation during flight are of value since flight operations may be expected to vary over time. This report describes the various kinds of disorientation and related experiences reported by a group of pilots flying several types of aircraft and compares these events with those reported by a group of pilots in 1956.[8,17]

METHOD

Pilots Reporting Disorientation

The reports of critical incidents involving disorientation were obtained from 336 pilots in the U. S. Air Force, Army, and Navy, all in active flight status. They were arbitrarily classified into five categories in terms of the aircraft they were flying at the time (Table 1). The majority had flown within the 5 days prior to responding to the questionnaire; only 12 had not flown within the past month. Their median age was 31; their median flight time in the current aircraft was 600 hours; and their median total flight hours were 2,000.

*The data collection for this study was accomplished at Ames Research Center, NASA, with the assistance of John D. Stewart and Charles C. Kubokawa and was supported by NASA Grant NGL 05-046-002 to San Jose State College

Table 1. The percentage of 321 pilots reporting disorientation in five types of current aircraft compared with the percentage of 137 pilots reporting these experiences in 1956.

	Transport N = 65	Training N = 105	High altitude N = 39	Single place jets N = 13	Helicopter N = 99	1956 N = 137
1. Although the wings were really level, I kept having sens[illegible] one or the other of the wings was down.	71	67	41	85	52	67
2. While observing a flare on a dark night, I thought it m[illegible]tic course, but it was really floating straight down.	18	15	3	31	33	23
3. On a dark night, I was confused about the stars and surface lights. Consequently, I became uncertain about the position of the horizon.	48	30	49	92	29	...
4. When I came out of a thick overcast, the horizon seemed severely tilted, although I was straight and level.	25	19	38	46	9	20
5. Following a loss of altitude while maintaining a constant heading, my ears cleared and I felt I was in a turn.	9	12	10	8	3	...
6. Although I was in complete control of the plane, I lost my sense of direction. I thought I was flying east, but I was actually heading north.	23	51	28	54	53	47
7. All at once, it seemed as if I was straight and level, although in reality I was in a turn.	40	40	44	46	34	66
8. I was very intent on the target and didn't check my altimeter. Suddenly I realized that I was too low, and abruptly pulled out with only a few feet to spare.	14	11	3	23	15	12
9. I became confused in attempting to mix contact and instrument flight cues for orientation.	37	31	44	38	31	31
10. When I levelled off after a bank, I had a tendency to over bank in the opposite direction.	42	40	46	92	44	67
11. I had a full view of the bay with the lights all around it. It seemed like a totally strange place, although normally it was quite familiar.	23	25	15	31	34	27
12. The sunlight coming through the propellers caused flicker, and a crew member became confused and very uncomfortable.	14	10	3	0	26	...
13. Following a climb on a constant heading, I felt I was in a bank. The instruments indicated straight and level.	26	29	18	15	21	...
14. On a routine patrol flight, I had a feeling of not knowing where I was, of getting turned around in direction momentarily.	34	43	26	38	45	39
15. During instrument flight, I found myself leaning to the right in the cockpit to keep myself vertical.	29	36	31	46	29	45
16. During straight and level flight, I felt that I was in a bank.	60	56	39	85	42	75
17. On a cross-wind landing, I noticed that I was drifting badly across the runway, but I failed to make any correction for it.	15	22	8	0	5	12
18. Following a steep, climbing turn, I felt I was turning in the opposite direction, but the instruments indicated straight and level.	32	26	23	46	31	35
19. As we flew through the fog, I became confused by the rotating beacon on the aircraft because it caused a flickering light in the cockpit.	42	23	28	46	22	...
20. As I climbed to high altitude, I had a feeling of isolation and of being separated from the earth.	23	22	15	38	24	[illegible]

Flight Experiences Questionnaire

All of the reports of disorientation experiences were obtained from a three-part questionnaire that included (1) a description of the purposes of the study and four demographic items, (2) a request for a written description of an experience with disorientation in the aircraft they were currently flying, and (3) a check list of flight experiences in the aircraft they were currently flying. The check list, which was derived from pilots' descriptions of vertigo (Table 1), was an abridgment and modification of a check list used in an earlier study of disorientation in jet pilots.[5] The pilots were asked to check those items in the list if they had had the same or a similar experience in the aircraft they were flying. The questionnaires were distributed in various squadrons and returned without identification of the respondent.

RESULTS

The ubiquitous nature and varied character of these reports of disorientation is evident from even a casual examination of the reports. The data indicate that most pilots experience these effects at one time or another. This is certainly not surprising since disorientation is a result of the interaction of several normal perceptual processes.[2-4,12,15]

Disorientation Reported on the Check List

The data from the check list (Table 1) show much variation from pilot to pilot. Of the 20 items on the check list, individual pilots checked from 0 to 16 with a median of 6. Only 22 pilots checked no items while 64 checked 10 or more (i.e., 93% checked at least one item). The check list included 15 items from an earlier study.[8] A striking feature of the results is the similarity of the responses of this group to those of the jet pilots in 1956. When these 15 statements were ranked in order of frequency of response for the two groups, the rank order correlation turned out to be +0.86 showing that the frequency of reports of disorientation has changed little in the past 14 years. It is evident from the items checked by one or more pilots that there is much similarity across the types of aircraft flown and that these pilots experience a wide variety of types of disorientation.

Disorientation is typically a complex perceptual process hence classifying the items is a difficult task.[12] Nevertheless, the data confirm earlier results[5] in showing that the most frequently reported type of disorientation involves uncertainty regarding the attitude and motion of the aircraft (Items 1, 7, 10). Visual disorientation (i.e., confusion or uncertainty regarding objects in the pilot's visual field) was much less frequently reported (Items 2, 3, 4). However, 92% of the 13 pilots flying alone in jet aircraft reported confusion of stars with surface lighting.

Light flickering at appropriate frequencies has been known for many years to produce annoyance, lowered alertness, various types of confusion, and even convulsions.[11-13,16,18] Furthermore, Berry and Eastwood[13,14] and others[16] have reported disorientation among helicopter pilots associated with flicker from the rotating wing. This study confirms their findings (Item 12), but indicates more frequent disorientation (Item 19) related to the flicker caused by the anticollision light (see also the report of pilot 327 below). Experimental evidence in a simulated cockpit[19] has shown that flicker in the range found in anticollision lights does not produce significant changes in EEG and nystagmus nor does it appear to cause changes in visibility. However, the duration of flicker was short, and the pilot was not engaged in a demanding task. Consequently, a substantial number of military pilots may be expected to experience discomfort, drowsiness, confusion, and even disorientation associated with flicker from the anticollision light

Geographical disorientation, incorrect orientation to compass points or places (Items 6, 14), was frequently reported by all groups on the check list Another problem related to geographical disorientation is the difficulty pilots sometimes have in recognizing familiar landmarks (Item 11) About 25% of the pilots reported this experience (known by the technical name of jamais vu, "never seen").

A much less commonly reported type of disorientation is "pressure vertigo" associated with pressure changes in the ear during changes in altitude.[3,20] Jones'[3] finding that about 10% of his pilots report this experience is confirmed by the results of the check list (Item 5) although Lundgren and Malm[20] found 18% of a group of pilots reporting "pressure vertigo."

Confirming the results of an earlier study, about 33% of the jet pilots reported experiencing the "break-off phenomenon," feelings of isolation and separation from the earth during flight, that leads sometimes to exhilaration and sometimes to fear or uneasiness.[5,13,17] Although jet pilots report the experience more frequently than others, it is also reported by all of the other groups including the helicopter pilots (Table 1). It is clear that the effect is not simply a function of high altitude flight.[5]

A final factor that may contribute to disorientation is the way the pilot directs his attention to the available information regarding orientation (Items 8, 17).[3] This is an old problem in instrument flight and is illustrated in the extreme case by a pilot directing his attention to one instrument to the exclusion of all other sources of information. As would be expected from the type of operations involved, such restriction of attention was reported most frequently by pilots of single place jets. To counter this effect some pilots and copilots in transport type aircraft have worked out a procedure using conversation between them to reduce undue concentration on the flight director during final approach As in earlier studies, a third or more of these pilots reported problems when they attempted to mix VFR and IFR sources of information (Item 9). Proponents of head-up displays have suggested that such arrangements make it easier to alternate between visual and instrument flight Whether this would lead to less disorientation remains to be demonstrated.

Reports of Critical Incidents Involving Disorientation

The pilots were asked to describe an experience involving orientation in space that was in some sense unusual or critical and might lead to some difficulty in flight. Of the 336 pilots who responded, 187 reported a critical incident before completing the check list (Table 1) The written description of the incident and a check list of descriptive terms related to the incident were used in an item analysis of each narrative One difficulty in collecting the data through the squadrons rather than in personal interviews was that the narratives sometimes lacked descriptive details that could have been obtained in an interview. However, it was possible to identify 40 incidents that occurred during operations in Vietnam. Consequently, a separate analysis was undertaken for these incidents to identify any unique experiences under these flight conditions.

It should be emphasized that these written narratives were merely a sample of occurrences recalled by the pilots in response to an open-ended request and therefore must be evaluated in these terms. Furthermore, the associated factors were uniformly complex The pilots cited many associated factors that in their minds contributed to the experience such as incorrect or inadequate visual information, fatigue and inadequate planning (particularly in the Vietnam group), lack of familiarity with the aircraft, faulty instruments, emergency conditions, carelessness, and inadequate attention. The descriptions made it clear that in many cases a series of disorientation events occurred, but in evaluating the incident, it was classified in the category judged to be predominant (see P-222 below) Some 15% of the incidents were impossible to categorize because of inadequate information (e.g., the pilot merely stated "I experienced vertigo")

Open-ended techniques of the sort used here have one important, potential virtue that is missing from a check list. They sometimes reveal unusual, new types of phenomena that pilots experience in flight. However, this was not the case with these reports of critical incidents in flight All that included adequate descriptive data were readily classified into one of the seven categories identified on the check list. Nor were there unique types of disorientation reported in Vietnam

The most commonly reported type of experience involved disorientation with regard to the attitude and motion of the aircraft (General, 52%, Vietnam, 45%). For example

Pilot 36 (P-36) (Vietnam). "I switched off my beacon, but developed vertigo. I felt that I was straight and level, but the instruments said I was climbing to the left I could look up and see the stars, but had no horizontal visibility."

P-296 (General). " conducting a turning rendezvous, lead rolled out after breakup and passed through a thin cirus cloud As I passed through same cloud and then exited, I felt as though lead and myself were inverted."

P-222 (Vietnam). "It was a low level flight in very bad wx . . . . Experienced inadvertent IFR. A/C was rolled to 90° angle of bank Copilot reaction was fast enough to right A/C before hitting the water. After righting the A/C, copilot became disoriented and raised the nose of the A/C to excessive angle. The pilot having by this time become oriented on instruments again took A/C and flew it out of the IFR conditions."

As with the check list, the next most commonly reported type of disorientation was judged to be predominantly visual, 15% of both groups reported visual disorientation, for example:

P-3 (General) "Flying below broken overcast . no moon . . . Was unable to distinguish between lights on the ground and the lights of other possible aircraft . . Each of us at one time or another during the flight attempted to take evasive action from lights on the ground or misinterpreted direction or altitude of other traffic."

P-13 (Vietnam). In a UH-1, "We were drifting far back and to the right of the formation. I could not detect the horizon nor tell the difference between ground lights and stars . . . . I couldn't tell how far away the next aircraft was. But judging how long it took to get repositioned, it must have been 100-400 meters."

P-277 (General). In clouds, "Commenced right turn to avoid high hills. Started climbing turn. Broke out and attempted VFR flight. Bright stars above caused feeling of being inverted . . . there were . . . bright lights in the area of the home base."

Geographical disorientation was reported both in Vietnam and elsewhere, but it was reported much more frequently for those incidents in Vietnam. Only 7% of the general incidents were judged to be geographical disorientation whereas 20% of the incidents occurring in Vietnam were placed in this category. This is not surprising, in the light of operating conditions in Vietnam, and the results support the emphasis placed on certain aspects of this problem.[21] For example:

P-12 (General). "I called the tower on final approach and turned on my landing lights. The tower told me he did not have me in sight. I realized that I was approaching to land at another airport . . . ."

P-31 (Vietnam). During a GCA. "Twice I felt like I was flying north when I was flying south."

P-108 (Vietnam). ". . . I could not see my compass. After making the assault and coming out of the LZ, I turned the wrong direction (180° out) and felt I was right. It took my (copilot) quite a while to convince me we were going the wrong direction."

Incidents involving the direction of the pilots' attention were much less commonly reported (General,7%; Vietnam,5%) than the three categories just described. For example:

P-15 (General). In a helicopter. "I observed the rotating beacon of another aircraft and could not determine what direction he was flying. I unconsciously devoted all my attention to that one beacon and ended up in a 30K (30 knot) climbing turn . . . . I was momentarily disoriented when I realized what was happening."

P-42 (Vietnam). "We were sent out to check a stream for possible sampans. Weather: ground fog and haze, light rain . . . . We were flying at 100-150 searching a streamline with our search light . . . . Suddenly the aircraft was in a left descending turn."

Critical incidents involving flicker vertigo, pressure vertigo, and the break-off phenomenon were recalled less frequently than the reports indicated on the check list. These were described only in six reports by the general group and not at all by the Vietnam group. An illustration of each is given below:

P-327 (General). "Anticollision lights flashing around on clouds made me want to believe aircraft in turn but instruments indicated not so. I cross checked copilot's instruments and they were the same as pilot's. I then disregarded sensations and stayed on instruments."

P-182 (General). "Left ear difficult to clear . . . as copilot during takeoff . . . . Pilot went into a climbing turn in clouds. The sensation of rolling inverted was uncontrollable."

P-85 (General). UH-1. "It was my first solo flight. After I pulled the A/C to a hover, I suddenly realized the A/C was drifting to the right. Corrective action was taken . . . . I had the feeling that I was completely separated from the surrounding area, as in 'limbo'."

DISCUSSION

The incidents reported by the pilots in this study as well as those from other studies over several decades make it clear that disorientation involving confusion with regard to the attitude and motion of the aircraft is the most commonly reported type of disorientation. Furthermore, the vestibular system is the primary sensory mechanism involved in this type of disorientation.[1-6,9,12,15] Three characteristics of the semicircular canals predispose the pilot to this type of disorientation, and these characteristics contribute to a conflict of sensory information with information from other sensory systems.[3,15] First, the semicircular canals respond to angular acceleration rather than to the velocity of rotation, which is the characteristic, subjective response to rotary stimulation. The canals may signal no rotation during a constant high velocity of rotation during a prolonged turn, or they may signal rotation in one direction during a deceleration while the actual rotation is in the opposite direction. Second, the afteraffects of rotation may continue for a prolonged period after the rotary acceleration has been reduced to zero (e.g., when the pilot turns to straight and level flight after a prolonged, constant rate turn). Third, if the pilot moves his head during a turning maneuver Coriolis couples stimulate the semicircular canals and produce strong, bizarre, nonveridical information that may result in improper action.[3,9,17]

A recent study of the sensitivity of airline pilots to angular acceleration has furnished additional evidence of the importance of the semicircular canals in disorientation. Clark and Stewart[22] using the oculogyral illusion as the indicator found that the thresholds for angular acceleration for 36 airline pilots range from 0.04 to 0.32°/sec² with a median of 0.11°/sec². These data show that pilots' sensitivity to angular acceleration is far below the angular accelerations present in many maneuvers in military aircraft. When such information is nonveridical, disorientation may result even for very low levels of angular acceleration. It has been well established that although pilots are taught to ignore motion information, they do in fact use such information in the operation of flight simulators and complain when such information is missing because the simulation is then not realistic.[23] Undoubtedly, such motion information is also used in flight to alert the pilot to motion of the aircraft and improve his efficiency in control tasks. The fact that such motion information may help in the control of an aircraft under certain circumstances while it may lead to disorientation under other flight conditions makes the confusion resulting from nonveridical information all the more difficult to control.

Spatial orientation and disorientation in flight are major historical and current problems in aerospace medicine.[7,9,10,12] Although there is some variation in the types of disorientation reported for different types of aircraft (Table 1), there is a striking similarity among them across some 14 years of flight experience. Furthermore, strikingly similar experiences have been reported by a number of investigators around the world.[2,3,9,11,12] This is well illustrated by a comparison of the data reported here with those of Kato and her associates at the Aeromedical Laboratory of the Japanese Air Self-Defense Forces.[9,12] They have carried out comprehensive studies of factors associated with disorientation in flight that go far beyond the purposes of this report. For example, they report no significant relation between vestibular function tests, anxiety scale scores, and disorientation although some positive

trends were found. Kato lists the following factors that contribute in important ways to disorientation: instrument flight, flying alone in formation behind a leader, flying in clouds (either day or night), head movements, and banking maneuvers. But more important for this study was the great similarity of her pilots' experiences to those reported above. Reports of confusion of motion and attitude of the aircraft were the most common in both studies. Furthermore, the description of the events showed much similarity. Some examples from Kato's studies follow. These have been translated into English. Her reports are in quotation marks, the numbers in parentheses refer to specific incidents cited in Table 1 or by particular pilots above

1. "An illusion of level flight while making a turn." (Cf. number 37, P-36)

2. "An illusion of tilting while flying as a wingman in a formation although the leader's plane was in level flight." (Cf. numbers 1 and 16, P-296)

3. ". . . after recovering a turn, feeling of over-bank in the opposite direction." (Cf. number 10, P-222)

Similarities between the studies in which visual factors were primarily involved are illustrated by the following incidents:

1. "Loss of the sense of the vertical (5 cases): while actually maintaining a normal position (4 cases) and while actually on his back (1 case). This is due to the subject's failure to distinguish between the stars and the lights of fishing boats in the sea or lights on the ground." (Cf. number 3, P-277)

2. "Autokinesis" (Cf. number 2, P-3)

Similarly, Kato found that 29% of her pilots reported geographical disorientation, but she did not give a specific description of such incidents. In this study, 23 to 54% of the pilots checked such items on the check list. (Cf. numbers 6 and 14, P-12, P-31, and P-108)

It is worth noting that the purposes of this study and Kato's were different in important respects; different methods were used and the nature of the interrogation was different in many ways. For example, Kato specifically inquired about Coriolis effects, subthreshold effects, and illusory pitching motions while this study did not. Similarly, this study was concerned with flicker "vertigo," pressure "vertigo," and the direction of the pilot's attention while Kato was not. In spite of this, there was substantial similarity among the studies and even with the 1957 report. Certainly no gross differences were found in the nature of the disorientation reported, and the results suggest that the relative importance of disorientation like "pilot error" accidents in general[6] has probably increased in the past decade. It is not surprising that this is so. No attempt will be made to describe the complex, perceptual processes involved in orientation in flight since that has been done by many others.[3-4] Nevertheless, it is evident from the reports that the pilot is a part of a highly complex man-machine system in which various types of information are available with respect to orientation to the earth and to other objects in space. Information from the pilot's visual and force environments (linear and angular acceleration) lead to normal perceptual processes that may be at variance with information from the instruments. Consequently, the information from his own perceptual systems, which is correct and used effectively during his life on the ground, may be either correct and useful or illusory and degrade flight performance, depending on the nature of the flight. Training devices of various types have been found to be useful in familiarizing the pilot with these effects.[11-18] Thus, "vision beyond sight" through the aircraft instruments must be used, and the pilot must learn to discipline himself to direct his attention to the appropriate instruments and consider his own perceptual information as untrustworthy. That this is no simple task is evident from these pilot reports as well as many others[9-12]

Disorientation in flight is not only a current problem in flight; it promises to be a continuing problem. Routine flight operations create orientation cues that result in "normal" perceptual processes that may be either correct or illusory. If the pilot directs his attention to incorrect or misleading information, he will probably become disoriented. The information displays related to orientation have changed little in the past decade. Although such information has made flight possible under a wide range of conditions, it has not eliminated disorientation. Certain types of disorientation will be reduced only if instrument displays are developed that for all pilots have the force, if not the substance, of information available during VFR flight. The illusory perception will still be there, but its weight in determining spatial orientation will be much less important.

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DISCUSSION

GUEDRY. The basic problem of disorientation in flight does not appear to have changed over the years. Yet wouldn't you agree that things are being done to reduce disorientation, in the field of training and improved instrument displays?

CLARK. I cannot really agree; instruments have changed little over the past decade, the basic flight instruments are still there and do little to provide what might be called 'vision beyond sight'. Improved displays are required to provide orientation cues which have the force of 'visual experience'. This is where training becomes important.

BENSON. One of the difficulties lies in the symbolic nature of the orientational cues provided by aircraft instruments; this is one reason why the aviator cannot accept such cues without qualification.

GUEDRY. I recently saw a pilot who felt that when he had two gyro attitude displays, disorientation was halved. If both instruments gave the same information he believed them, rather than his own sensations.

CLARK. Yes. I have come across this type of situation. A comparable incident is described in my paper where the pilot reported cross checking his own instruments with those of his co-pilot to make sure that it was his own sensations which were in error.

ALLEN. Have you identified the problem of disorientation associated with catapult take-off at night?

CLARK. I have no data of these incidents, but I believe we will hear from Dr Cohen, later in the meeting, about work which is relevant.

ALLEN. I suspect that there may not be survivors of that type of incident.

BENSON. The last comment raises a point that has always worried me. The disorientation accident can occur, perhaps frequently does occur, when the pilot does not realise that he is disorientated. The disorientation incidents we hear about are commonly those in which there was sensory conflict; the pilot was aware of his disorientation. We know that aircrew all suffer from disorientation at some time or other during their flying career, but in what proportion of flights do they have this disability? Have you any ideas of how we can get reliable data about the frequency of disorientation?

CLARK. I don't know how one could do this. Attempts have been made of course, as in the US Navy where flyers were asked to make a report every time they had an incident. But aviators can be reluctant to talk about unusual sensations, they think that they may be a little bit odd and do not wish to broadcast the fact.

MALCOLM. I would like to raise again the role of the unnaturalness of flight instruments in the aetiology of disorientation. Do you have any recommendations to make about the development of instruments which provide either a more natural presentation of information or a display which can be used in a more natural way?

CLARK. I am convinced that improved displays would reduce the incidence of disorientation and we have already mentioned how redundant information can strengthen the aviator's acceptance of instrument cues. Yet I do not think that instruments, no matter how good, will ever completely prevent disorientation. I have no suggestion to make concerning the way instrument displays could be improved.

DOBIE. You have shown that disorientation happens in many types of aircraft and operational roles and is hence an ubiquitous phenomenon. Most aircrew have had experience of disorientation - it has been demonstrated to them in the flight environment. Do you not think that our task is to teach them how to live with disorientation rather to demonstrate disorientation to them on the ground?

CLARK. Your point is a valid one and I agree with you that the place to learn about how to cope with disorientation is in the air. Nevertheless I feel that student aviators and perhaps many experienced pilots benefit from the demonstration, on the ground, of illusory vestibular sensations. It reminds them of the strength of these illusions and provides a justification for the oft repeated instruction - believe the instruments.

GILSON. Do you think that the problem of disorientation has been changed either in magnitude or frequency of occurence by the developments of higher performance aircraft with their greater accelerative forces and consequently greater stimulation of the vestibular system?

CLARK. The incidents reported in the recent survey were much the same as those reported by jet pilots in 1956. It would seem that pilots of high performance aircraft suffer the same type of disorientating experiences as pilots of other aircraft. One might expect the incidence and intensity of incidents was higher but the questionnaire provided no direct evidence of this.

A REVIEW OF UNITED KINGDOM (RAF AND ARMY) STATISTICS ON SPATIAL DISORIENTATION IN FLIGHT 1960-1970

by

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INTRODUCTION AND AIM

1. This paper is based on the Royal Air Force Directorate of Flight Safety records of investigation into flying accidents where disorientation was a confirmed or probable cause. The period of review is the decade 1960-1970. Prior to this period, and in fact extending back into World War 2, disorientation received little if any mention in the accident records despite there having been many accidents in the 1940s and the 1950s which today's investigation boards would certainly ascribe to this cause. The paucity of early records of the phenomenon stemmed from a lack of understanding on the part of the pilots who experienced it and survived and, probably to an even greater degree, from the pilots' fears that an attack of "the leans" - or whatever name they chose to give to their discomforting experience - indicated a lack of fitness for their duties if formally reported. However, the advance of aeromedical training provided pilots with a greater understanding and awareness of the problem and during the 1960s an attack of disorientation gradually ceased to be a rather shameful secret to be whispered, if at all, no further than a squadron coffee-bar.

2. The aim of the paper is to present an analysis of the RAF/Army disorientation occurrences and, from the findings, to seek any areas where research on aeromedical lines might be profitable. The author is conscious of treading the fringes of the aeromedical field in which he is not competent and, whilst attempting to restrict any comments and conclusions to the operational and flight safety fields, apologises for any occasion on which he may have transgressed the boundary.

DISORIENTATION STATISTICS

3. Figure A shows the overall RAF/Army record of disorientation accidents and incidents for the period of review. Incidents are occurrences where minor or no aircraft damage was sustained, most of which are straightforward pilot reports of a disorientation experience; accidents are occurrences where serious or write-off damage was sustained and include a high proportion of fatalities. A fatal accident is only included as a disorientation case if the investigation board clearly found this to be the probable cause. Annual flying hours decreased by a small amount over the whole period and, with one exception, there is no special significance in the way the disorientation figures vary throughout the period; the exception is the peaking of the incidents in the second quinquennium which is almost certainly due to a publicity campaign in the middle period which acknowledged the existence of the problem and encouraged pilots to report their disorientation experiences. The campaign may also have led investigation boards to establish, with a high degree of probability, disorientation as a cause of certain fatal accidents in the second half of the period, producing the increase apparent in the figures. In other words the higher figures for the second half are considered to be nearer to the true level than those for the earlier years.

AIRCRAFT TYPES INVOLVED IN DISORIENTATION OCCURRENCES

4. The first step in the analysis of the statistics was to classify the record broadly by aircraft types involved; the table at Figure B gives the result. To establish any significant predominance of one aircraft, or group of aircraft, it is necessary of course to determine the proportion of flying effort by the type or types in the organisation providing the total sample. The figures given show that 5 aircraft incurred significantly more disorientation occurrences than the rest of the aircraft in the records, namely, producing 83% of the total disorientation occurrences whilst providing only 31% of the total flying. This group comprised the Canberra, employed mainly on reconnaissance and low-level strike; the Hunter, reconnaissance and close air support; the Lightning, air defence; the Jet Provost, basic pilot training; and the Sioux helicopter, Army observation.

5. The presence of the Sioux in the group is explained by the fact that until very recently the aircraft was not fitted with a complete instrument flying panel and flying in Instrument Meteorological Conditions (IMC) was not permitted; however, Sioux pilots in the nature of their role inadvertently entered IMC on several occasions and were then inadequately equipped to withstand and overcome disorientation effects. Of the remaining 4 aircraft, the Jet Provost is flown a considerable amount by very inexperienced solo student pilots and it could be expected that the risks of disorientation are particularly high with this class of pilot; the Canberra, Hunter and Lightning are all aircraft whose role demands more extreme manoeuvres than any other aircraft, together with high rates of climb and descent which bring rapid changes in flight conditions. It seems therefore that there are satisfactory explanations for the appearance of these aircraft in the "higher risk" disorientation group. A corollary of this aircraft grouping, implicit in the table, is that pilots of the heavier and slower aircraft, in roles where only moderate manoeuvres and less rapid changes of flight conditions are involved, are less exposed to disorientation - a conclusion which could be regarded as a statement of the obvious, but which statistical confirmation is nevertheless welcome.

CLASSIFICATION OF DISORIENTATION ACCIDENTS

6. The next step was to analyse and classify the disorientation accidents in order to determine any significant pattern and to identify any particular circumstance which might be predominant. The results, covering the total of 29 accidents in the period, are tabulated at Figure C. In 18 of the accidents the pilot

Fig. A

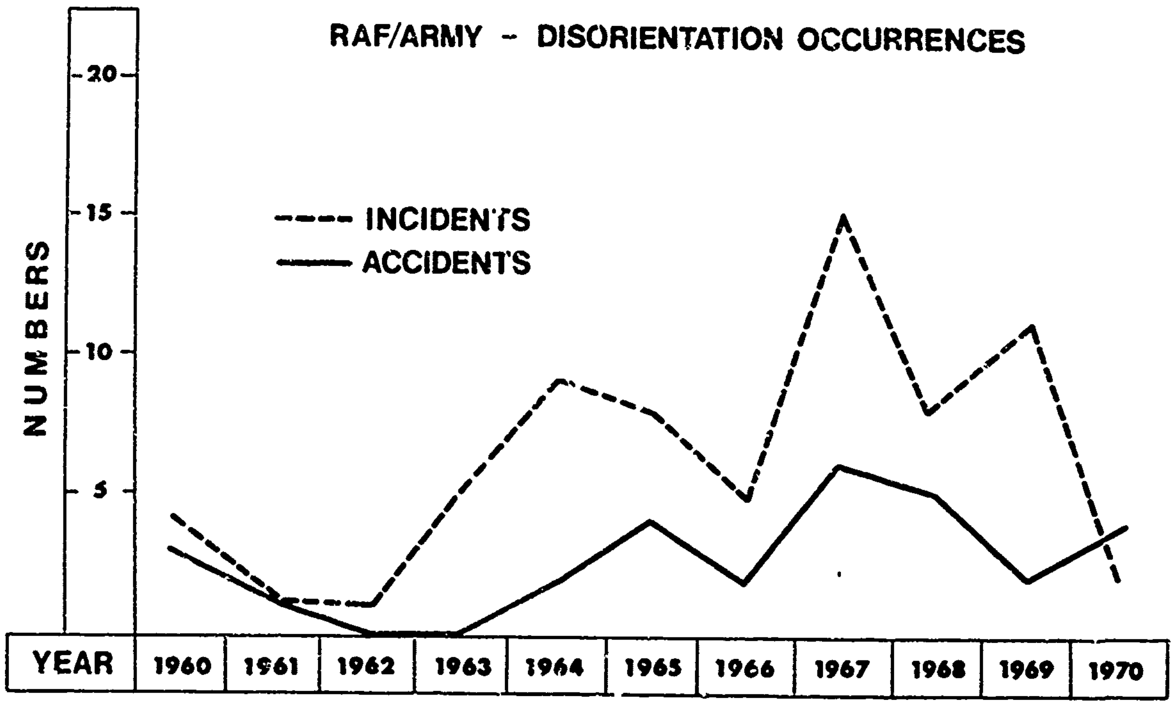

Fig. B

AIRCRAFT INVOLVED IN DISORIENTATION OCCURRENCES 1960-70

TYPE	PERCENTAGE OF DISORIENTATION OCCURRENCES	PERCENTAGE OF TOTAL FLYING TIME
CANBERRA J.PROVOST HUNTER LIGHTNING SIOUX	81%	31%
OTHER AIRCRAFT	19%	69%

Fig.C CLASSIFICATION OF DISORIENTATION ACCIDENTS RAF 1960-1970

Serial	Disorientation Cause	Accidents	Aircraft and Relevant Detail
1	Loss of control after entering IMC during manoeuvre	9	5 Canberra - day; 3 low level, 2 high level
			4 Hunter - day; 3 low level, 1 high; 3 inexperienced
2	Loss of control in IMC, level or descending	6	3 Jet Provost - 2 night; 3 inexperienced
			2 Scout - 1 night; 1 inexperienced
			1 Hunter - day; low level navex
3	Flying 'contact' by misleading external references. Disorientation unrecognized by pilot	6	2 Hunter - day; 2 low level, bright haze; 1 inexperienced 1 Hunter - night; descending in moonless haze
			1 Canberra - day; sun glare on landing
			1 Jet Provost - night; shortly after take off; inexperienced
			1 Scout - night; moonless conditions after searchlight exercise; inexperienced
4	Loss of control after losing formation leader in IMC	3	3 Hunter - day; 2 inexperienced
5	Loss of control in IMC due to lack of aircraft IF facilities	5	5 Sioux - 3 night; 2 inexperienced; aircraft now fitted with I/F panel

was killed and the cause could not be conclusively established, but these 18 accidents were included in view of the investigation board's formal findings, in each case, of disorientation as a probable or possible cause; in fact, in almost all of these cases the finding was very near to certainty.

7. The following points either emerge from Figure C or should be borne in mind when considering what conclusions can be drawn from the analysis it provides:

a. With the exception of the Lightning all the aircraft which predominate in the total record of disorientation (Figure B) also predominate in the accidents. However, the 5 Sioux helicopters in Serial 5 may be regarded as of little significance for this study. For the whole of the review period this aircraft was unequipped, and not cleared, for instrument flying; it was to be expected therefore that on the occasions where instrument conditions where inadvertently entered disorientation would be likely to follow rapidly.

b. The most frequent cause of disorientation accidents, Serial 1, is revealed as the sudden entering of IMC in conditions of high "g" and large angles of bank and pitch. These accidents clearly highlight the flying skill, together with rapid physical and mental readjustment, required of a pilot in such conditions.

c. The cause under Serial 4 is a modified form of Serial 1 but merits separate treatment not least for the reason that any remedial measures would be of a very specialised nature. The disorientation situation on losing formation in cloud is compounded, as the author knows from experience and from many conversations with pilots, by the pilot suffering rolling or banked sensations - often quite severe - up to the moment of losing sight of the formation leader: his problem then of rapid transfer to accurate instrument flight is significantly increased.

d. The accidents under Serial 2 confirm what is probably a generally accepted fact, that even in conditions of little stress and no sudden confrontation with IMC, pilots, especially if inexperienced, may not possess or exercise sufficient skill to withstand disorientation and fly correctly on instruments.

e. The accidents under Serial 3, all but one of which were fatal, have been classed under disorientation although they differ markedly from all the other accidents in that the pilots did not appear to lose control of the aircraft on instruments, but continued to fly by misleading external references, invariably including an indistinct horizon, until the aircraft hit the surface. If this behaviour is accepted as a form of disorientation it differs from all other forms in remaining undetected by the pilots, who continued to fly in what they appear to have been convinced was a safe and correct attitude up to the moment of the crash.

f. The table also records the night flying accidents and those involving experienced pilots. The proportion of night accidents and accidents by inexperienced pilots are both approximately double the figure to be expected from the amount of night flying carried out and the experience-spectrum of the squadrons. This serves to confirm two generally-held opinions, that night flying and inexperience are factors predisposing to disorientation.

g. Of all the pilots involved in the accidents only one is recorded as having had any significant medical history such as previous disorientation or recent ear/throat infection. This pilot had been receiving treatment, not under RAF medical services, which included the use of the drug belladonna.

h. It is perhaps noteworthy that there have been no accidents caused by disorientation during landing approach, a type of accident which has occurred a number of times to other operators. The Canberra landing accident in Serial 3 barely qualifies for this category when the details are examined, being occasioned by a loss of control at the point of touch-down caused by a combination of bright sun on a salt-obscured windscreen and an engine malfunction.

CLASSIFICATION OF DISORIENTATION OCCURRENCES

8. The final table, Figure D, shows the classification of disorientation causes for all occurrences, that is accidents and incidents, for which details are available. The 5 Sioux accidents, due to inadequate aircraft instrument flying facilities, have been omitted, as have 3 similar Sioux incidents. The following points should be noted:

a. Serial 1-4 repeat those of the Accident table Figure C, and it can be seen that these accident causes also figure largely as causes of incidents.

b. Serials 5-9 represent 5 further causes of disorientation definable from a study of the incident reports. The high figures for ear infection and head movement cases are particularly noteworthy; furthermore, these 2 causes, together with reaction to aircraft lights (Serial 8), may well have operated in some of the accidents categorised in Serial 1-4 although the fact could not be determined from the evidence available.

Fig.D CLASSIFICATION OF DISORIENTATION OCCURRENCES RAF 1960-1970

Serial	DISORIENTATION CAUSE	ACCIDENTS	INCIDENTS
1	Reaction to manoeuvre in IMC	9	3
2	Reaction to entering IMC level or descending	6	11
3	Misleading external references (undetected)	6	9
4	Formation in IMC	3	3
5	Ear infection or other physical predisposition	- *	14
6	Landing Approach in IMC	0	3
7	Pilot's head movement	- *	9
8	Reaction to external aircraft lights in IMC	- *	3
9	Reaction to manoeuvre in VMC	0	4

* See text para 8b

c. Although not shown in the table the proportion of night accidents confirmed what was deduced from the accident records, that night flying can predispose to disorientation. However, a similar confirmation was not obtained for inexperienced-pilot cases. The proportion of inexperienced pilots in the incidents tabulated was considerably lower than in the accidents and did not support the inference drawn from the accidents that inexperience can predispose to disorientation. It may be that in spite of the increased understanding of disorientation in flying units some inexperienced pilots overcome the occasional disorientation problem but prefer not to report it.

RELEVANT AIRCRAFT DESIGN FEATURES

9. The possibility that some characteristic of cockpit structure or configuration might have a bearing on disorientation was considered, the 2 most likely factors being pilot's seat position in relation to the aircraft centre line, and canopy structure. Analysis of the aircraft types in all the occurrences failed to reveal any statistical link between off-set pilot seating and disorientation. Analysis of canopy structures revealed that the 5 aircraft in the group incurring the highest disorientation rate have cockpit canopies which are either completely clear and frameless or have minimal framework, thus producing a bubble effect within the cockpit in certain conditions. It is not suggested that this reveals a design defect in these aircraft; because of their roles, referred to in para 5, they require the provision of maximum clear field of view for the pilot. However, this feature, possessed by virtually all military aircraft designed for these roles, undoubtedly denies the pilot visual reference lines present in more enclosed cockpits.

CONCLUSION

10. Whilst emphasising that any comments under this heading are offered as a layman's view in the aeromedical context, the author would draw attention to the main points arising from this survey:

a. Of the classified causes of disorientation the various factors listed in Serials 5-9 of Figure D are ones which should be reducible by effective supervision and indoctrination, and by high standards of flying training.

b. To remedy those disorientation causes responsible for serious accidents as well as incidents, Serial 1-4, additions or modifications to instrument flying training could be worth seeking. It might be possible to devise methods of simulating the sudden entry of IMC either in ground simulators or airborne training which would arm pilots against this hazardous situation, although this would not necessarily assist in the problem of undetected disorientation, Serial 3.

c. The need for the modified training techniques suggested above appears to be greater in those aircraft employed in rapid-manoeuvre roles and fitted with clear or relatively unobstructed canopies.

11. This paper has attempted to identify, from the RAF/Army records, the significant factors and hazardous situations in the disorientation problem from a military point of view; the author hopes that it may provide some points from which could be developed an aeromedical contribution to flying training, particularly in the sensitive roles and circumstances described, that will save lives and aircraft which continue to be lost from known disorientation causes.

DISCUSSION

WOLBARSHT. Is there a possibility that the pilot, after losing the lead aircraft when flying in formation, is not immediately able to gather information from the instrument panel? If he currently flies several types of aircraft, a momentary confusion as to which panel arrangement is presently appropriate could be the basis of a short term, and perhaps fatal disorientation.

LOFTING. In our 'loss of leader' accidents, none of the pilots were currently flying more aircraft than the subject aircraft and its training variant. I can therefore do no more than agree with the questioner's suggestion; we have no facts to support or contradict it.

DOBIE. In your review of RAF disorientation accidents you found a high incidence when visibility conditions were of the 'fish-bowl' type, but none during descent and landing. Could it be that in the former situation there was a tendency to look-out even though reliable visual cues were minimal, whereas in the latter the pilot tended to use instruments and hence have reliable visual cues? The situation described would appear to be explicable on this basis.

LOFTING. If the pilot looks outside in conditions of poor VMC, as he will be forced to do in tactical/combat situations, he will be vulnerable to disorientation. On an IMC approach to land the pilot, flying on instruments, will be well provided with visual (instrument) inputs, but if he looks outside, as he must eventually do at his minimum approach height, he may then face an external visual situation similar to the pilot in the tactical situation. RAF experience suggests that our pilots have somehow (as a result of training techniques) largely avoided being misled by illusions on IMC approaches, though accidents of this nature have been reported by other operators.

During this discussion the possible benefit of the use of Head Up Displays (HUD) was raised. It was suggested that this type of instrument makes it easier for the pilot to transfer from external references to instrument reference. The time taken to re-establish aircraft orientation should be reduced, so the opportunity for the pilot to become disorientated should also be less than with conventional instruments. However, at least one speaker pointed out that the cues provided by the HUD were still symbolic and though a lot of information was presented within a small visual angle, coning of attention had been reported with this type of dis-

It was agreed that information about the relative incidence of disorientation in aircraft with a Head Up Display and in those with conventional instruments would be valuable.

ORIENTATION-ERROR ACCIDENTS IN ARMY AVIATION AIRCRAFT

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To initiate the action necessary to establish the magnitude of the orientation-error problem in Army aviation, an interservice research program was organized under the joint sponsorship of the U. S. Army Aeromedical Research Laboratory, the U. S. Army Board for Aviation Accident Research, and the Naval Aerospace Medical Research Laboratory. The first step was the construction of an operational definition of an orientation-error accident. The assimilation of data pertaining to the incidence and cause of such accidents and their actual and relative costs in terms of fatalities, injuries, and aircraft damage was then set as the working object · of the program. Accordingly, the decision was made to implement a five-year longitudinal study of all mc· ·r and minor orientation-error accidents involving Army Aviation flight operations beginning with July 56.

Incidence and cost data are presented for all Army Aviation major and minor orientation-error accidents detected in the search of the accident files for the period July 1966 to July 1967. Separate and totalized statistical data are provided for fixed wing and rotary wing aircraft as well as for accidents occurring in Vietnam and those occurring elsewhere.

Orientation-error accidents arising from a pilot's erroneous perception of the true spatial motion or true spatial attitude of his aircraft have been long recognized as a significant aviation safety problem. In the flight environment man finds little difficulty in correctly perceiving his spatial orientation when clearly defined geographical landmarks are available without illusory artifact. When these visual references are not present, as is often the case during bad weather or night flight missions, man's vestibular mechanisms and other related nonvisual sensory processes become the predominant source of internally derived spatial orientation information. Though these systems function well in the normal terrestrial environment, this is not the case in the flight situation. Here man can be exposed to simple and complex combinations of forces and torques that elicit sensations of movement and perceptions of orientation which may be in complete conflict with the actual motion or attitude of the aircraft. Even with clear visibility, the same form of erroneous sensations and perceptions can result if the pattern of the external environment is conducive to the elicitation of visual illusions. For example, pilot errors can arise in the perception of aircraft motion during hovering flight over fast moving water or within wind driven smoke or dust clouds; in the perception of aircraft attitude when sloped terrain is interpreted as being level, or a tilted cloud border or slanted tree line is perceived as representing the horizon; or in the perception of altitude during flight over water or similar planar terrain without clearly defined landmarks.

When such errors in spatial perception occur, the result may merely be a mild confusion of the pilot as to some motion, attitude, or altitude parameter. If the error is quickly recognized, the pilot can take action to establish his true perspective in space by using some other orientation reference whether it be a specific instrument or a different set of exterior landmarks. At the other extreme, the pilot may suffer intense vertigo that seriously degrades his control ability. Equally dangerous is the situation where the pilot unknowingly experiences disorientation and controls his aircraft in accordance with his erroneous concept of its true motion. In all cases, there exists the potential for an orientation-error type accident, with the level of probability of occurrence keyed to such factors as the type of aircraft being flown, the type of mission being undertaken, and the phase of flight where the disorientation event is manifested.

Though such disorientation experiences have received considerable research attention from both the aviation safety and aviation medicine personnel in the past, the advent of more demanding cost-effectiveness programs will greatly influence the extent of the support to be given to such research projects in the future. In broad terms, the research man-hours and dollars to be expended on a given operational problem will be scaled in accordance with the actual magnitude or cost of the problem. For the case of pilot disorientation research in military aviation, the extent of support to be made available will be keyed to the exact magnitude of the orientation-error accident problem. In effect, research support will, directly or indirectly, be based on the over-all cost of orientation-error accidents in terms of personnel, aircraft damage, and degraded mission performance. Unfortunately, though spatial orientation difficulties are known to contribute to Army aircraft accidents (1-4), few quantitative data are available to adequately describe the actual magnitude of the orientation-error accident problem either in terms of the incidence and cost of such accidents in relationship to themselves or in their proportionate relationship to the over-all accident problem.

With the objective of gaining such data for orientation-error accidents occurring in Army aviation, the authors organized an interservice research program under the joint sponsorship of the U. S. Army Aeromedical Research Laboratory (USAARL), U. S. Army Board for Aviation Accident Research (USABAAR), and the Naval Aerospace Medical Research Laboratory (NAMRL). The basic plan of the program is to conduct a five-year longitudinal study of the USABAAR accident records so as to identify all major and minor orientation-error accidents that occurred in Army Aviation flight operations beginning with July 1966. In this report, a summary is made of the incidence and cost of all orientation-error accidents detected in the search of the accident files for the period July 1966 to July 1967. The data cover all Army Aviation flight operations involving all fixed wing aircraft and all rotary wing aircraft. Separate and totalized statistical data are provided for both forms of aircraft as well as for accidents occurring in Vietnam and those occurring elsewhere.

To initiate the program it was necessary to establish a workable definition of the class of accidents to be identified as orientation-error accidents. It will be recognized by investigators actively engaged in aviation safety research that the cliché "easier said than done" is most appropriate for this task. There would be little difficulty in identifying accidents involving pilot disorientation if the latter always manifested itself in the extreme where a pilot calls out that he is experiencing severe vertigo and is having difficulty controlling his aircraft. Similarly, when visibility is poor or the visual environment conducive to illusions, the task of identifying an accident as being related to difficulty in maintaining spatial orientation is not too difficult. However, when the factors surrounding a given accident become borderline as to whether or not a pilot made an orientation error, it is of the essence that the accident classifier be given some appropriate criteria to help him make the classification decision. Although any definition of orientation error will be compromised at times by one or more unique features of a given accident, it was felt that a workable classifying system could be developed for the majority of the accident types to be encountered in our review.

DEFINITION OF ORIENTATION-ERROR ACCIDENTS

First, the term orientation is considered to involve the correct determination of the dynamic position and attitude of an aircraft in three-dimensional space. The key word here is dynamic, which implies that full knowledge of the motion as well as static attitude or position of an aircraft is required to define its instantaneous spatial orientation. For a pilot to have a full comprehension of his orientation, it is essential, for example, that he be able to describe the static pitch and roll attitude of his aircraft relative to some external reference such as the Earth-vertical defined by the gravitational vector; his yaw attitude relative to some geographical heading; the linear velocity of the aircraft, with or without attendant linear acceleration, in terms of forward, left-right, and up-down motions; and the angular velocity of the aircraft, with or without attendant angular acceleration, in terms of roll, pitch, and yaw rotary motions of the aircraft. Thus, for a fully oriented fixed-wing aircraft pilot, typical information inputs would include knowledge of the forward speed of the aircraft, the vertical speed in terms of either climb or descent rates, sideward drift velocity, pitch and roll attitude, as well as bank angles, angle of attack, et cetera. In landing or rendezvous operations, recognition of the effects of these aircraft motions on absolute distance must be made to ensure that the aircraft does not undershoot or overshoot a preselected touchdown or rendezvous point.

The rotary-wing aircraft pilot requires similar information. However, during low-level hovering conditions, additional information is required in the form of linear velocity in the backward as well as forward direction. Unfortunately, the majority of the currently operational helicopters do not have instruments that provide this backward velocity or, for that matter, sideward drift velocity, information. The usual lack of short-range radar altimeters in helicopters is another problem confronting the rotary-wing aircraft pilot during low-level operations performed with poor ground visibility.

By this definition of the word orientation, it follows that a pilot will be considered to have made an orientation error whenever his perception of the motion and attitude of his aircraft differs from the true motion and attitude; i.e., the true orientation of the aircraft. The exact magnitude of an orientation error will obviously vary over a wide range. In the case where a pilot suffers severe vertigo and completely loses all perception of either aircraft motion or aircraft attitude, the probability of a large-scale orientation error is high, as is the probability of an accident if the disorientation is prolonged or is experienced at a critical control phase within the flight. In another case, the pilot may sense or feel that the aircraft is climbing or turning when in actuality it may be flying straight and level. If during this disorientation experience the pilot accepts that his sensations define the orientation of the aircraft, then an orientation error is present. However, if he realizes that his sensations are in conflict with another input, say the aircraft instruments, and intellectually arrives at the correct judgment of the true motion and attitude, then though the pilot is experiencing disorientation, an orientation error does not result.

Initially, then, an orientation-error accident can be defined as one that occurs as a result of an incorrect control or power action taken by a pilot due to his incorrect perception of the true motion and attitude of his aircraft. Using this definition, an accident classifier can place primary emphasis on determining whether or not the accident involved an erroneous judgment of orientation on the part of the pilot. It follows that questions pertaining to the causes of the orientation error, or its manifestation to the pilot, need not be immediately answered during the initial classification.

There must, however, be several qualifications to this definition. For instance, the accident situation must be one in which the demands on pilot skill are reasonable. To illustrate, consider a helicopter pilot who has a main rotor strike as a result of landing from a hover in a nonlevel attitude, say with an excessive roll angle. This is an orientation-error accident involving incorrect perception of aircraft attitude. The causes of the orientation error could be much varied, ranging from inattention to instruments, a tilted horizon line, visual illusions produced by a nearby moving aircraft, or distraction. A simple, but essential, assumption is that the pilot did not deliberately fly his aircraft into the ground. However, if in a similar landing from a hover situation, a nearby helicopter flies over the given aircraft and produces severe rotor downwash or turbulence, and the end result is a similar rotor strike, the accident would not be classified as an orientation-error accident. It is not reasonable to expect the pilot to maintain both perception and control of aircraft orientation under these conditions. In like manner, a tail rotor strike resulting from excessive flare applied by the pilot in a landing formation to

avoid striking another aircraft making an unauthorized takeoff would not be classified as an orientation error accident. But again, if this tail rotor strike occurred during a routine uninterrupted landing, it would fall into our classification since the pilot's perception of closing rate or pitch angle was incorrect.

A further qualification involves accidents associated with navigation errors. Though knowledge of heading is pertinent to orientation, accidents involving navigation mistakes, and only navigation mistakes, are not classified as orientation-error accidents. That is, if a pilot strikes a hillside as a result of flying a course of 100 degrees instead of 200 degrees, the error is one of navigation, not orientation. In this respect, the word misorientation has received some usage to account for navigation errors. However, if in addition to being on the wrong course or heading, a pilot is having difficulty controlling his aircraft and an accident results because of this difficulty, an orientation-error accident classification would generally result.

Accidents resulting from collision with unseen objects, e.g., a wire strike, are also not included if the collision occurs during normal controlled flight. However, if a hovering pilot allows his aircraft to drift backward, without detection, and finally to impact against an unseen object, an orientation-error classification would result. That is, collisions of this sort are included only when they derive from an orientation error.

As qualified by all of the above, an orientation-error accident is thus said to occur whenever an accident results from a pilot's incorrect perception of his true motion and attitude in space. The orientation error may range from a complete loss of all knowledge of orientation to simple confusion as to only one of the many motion and attitude parameters required to be recognized by the pilot. Or, as mentioned previously, the pilot may never realize that the motion or attitude of his aircraft is gradually changing so as to be soon unfavorable to safe flight.

ACCIDENT-FILE SEARCH PROCEDURES

With this definition of orientation-error accidents serving as a classification reference, a comprehensive search was made of the USABAAR accident files to determine all major and minor accidents (as defined in refs. 5,6) that occurred in Army Aviationflight operations from July 1966 to July 1967. This search involved having a classifier, with previous experience in detecting disorientation/vertigo accidents, read each and every accident brief in the master files. These briefs covered all types of accidents in all types of aircraft, fixed wing and rotary wing, and included accidents occurring in Vietnam as well as those occurring in all other locations.

For redundance, the entire accident file was also searched by means of the coded summaries that USABAAR prepares for each accident. These summaries, in punched card form, list the essential background data of a given accident as well as the primary causal factors. The objective was to obtain the accident identification number of all accidents involving vertigo, disorientation, poor visibility, bad weather, obstructed vision, night flight difficulties, visual illusions, and the like.

Upon completion of these two searches, the authors reviewed the accident briefs independently for the purpose of establishing whether or not an orientation-error accident classification would result. In addition, the comprehensive master file on each suspect accident was obtained and reviewed. Whenever there was serious question as to the contribution of orientation error to the accident, or where equally weighted alternative causal factors existed, then the accident was not included in the classification. The net effect of this policy is to give a conservative estimate of the magnitude of the orientation-error accident problem.

An analysis was then made of the cost of each of these accidents in terms of personnel and dollars. In addition, the statistical section of USABAAR was asked to compile equivalent incidence and cost data pertaining to 1) accidents of all forms, and 2) accidents considered to involve pilot-error factors. These data are used to establish a baseline reference for evaluation of the relative magnitude of the orientation error accident problem.

RESULTS AND DISCUSSION

Before the operational significance of orientation-error accidents can be placed in proper perspective, it is necessary to have at least a cursory understanding of the incidence and costs of aircraft accidents in general. To provide this background, the first section to follow is devoted to describing the over-all cost of all Army Aviation aircraft accidents, regardless of type or location, that occurred during the year beginning July 1966. In a second section, equivalent data in a near identical format are presented to separately identify those accidents in the first section that were classified by USABAAR as involving one or more pilot-error factors. Cost statistics pertaining to only orientation-error accidents are then presented in a third section. By using these three sets of data as independent references, it then becomes possible to establish some quantitative insight into the relative, as well as actual, cost of orientation-error accidents in Army Aviation flight operations. Selected comparative relationships of this type are presented in the last section of the report.

ALL TYPES OF AIRCRAFT ACCIDENTS

The data presented in this section describe the incidence and cost of all major and minor aircraft accidents involving all Army Aviation flight operations. Separate data groupings are provided for accidents involving only fixed wing (FW) aircraft, only rotary wing (RW) aircraft, and their combined total. In addition, for each of these three statistical groupings, the data are divided into those accidents that occurred in Vietnam, those accidents that occurred elsewhere, and their combined total. Since the vast majority of the accidents that do not occur in Vietnam (VN) take place within the continental limits of the United States, the abbreviation US is arbitrarily used to denote all accidents that do not occur in Vietnam. It should be realized then that the US data grouping will include a small number of accidents that may have occurred, for example, in Europe, Africa, or elsewhere. A second point to be stressed is that the VN data pertain strictly to accidents,

not losses due to enemy action.

In the interpretation of the accident statistics to follow, it becomes possible to com[illegible] and RW accident incidence or VN and US accident incidence only when some common measures of aircraft utilization are selected as weighting factors. To establish such comparative references, percent aircraft inventory, total flying hours, and total aircraft landings are used as basic weighting data in this report. These data, as well as the incidence and cost statistics presented in this section, are summarized in Table I.

TABLE I

ACCIDENT SUMMARY - ALL ACCIDENT TYPES
JULY 1966 TO JULY 1967

ACCIDENT INDEX	ALL AIRCRAFT			FIXED WING AIRCRAFT ONLY			ROTARY WING AIRCRAFT ONLY		
	Accidents			Accidents			Accidents		
	U.S.	Vietnam	All	U.S.	Vietnam	All	U.S.	Vietnam	All
Major Accidents - Number	205	531	736	48	86	134	157	445	602
Minor Accidents - Number	23	43	66	5	4	9	18	39	57
Total Accidents - Number	228	574	802	53	90	143	175	484	659
Aircraft Inventory - Percent Total	66.69	33.31	100.00	25.75	6.38	32.13	40.94	26.93	67.87
Total Flying Hours (in 000's)	1,944	1,681	3,625	459	358	816	1,485	1,323	2,808
Total Landings (in 000's)	7,078	4,318	11,396	830	348	1,178	6,248	3,971	10,218
Major Accidents per 100,000 Hours	10.55	31.59	20.31	10.47	24.05	16.42	10.57	33.63	21.43
Minor Accidents per 100,000 Hours	1.18	2.56	1.82	1.09	1.12	1.10	1.21	2.95	2.03
Total Accidents per 100,000 Hours	11.73	34.15	22.13	11.56	25.17	17.52	11.78	36.58	23.46
Major Accidents per 100,000 Landings	2.90	12.30	6.46	5.78	24.73	11.38	2.51	11.21	5.89
Minor Accidents per 100,000 Landings	0.32	1.00	0.58	0.60	1.15	0.76	0.29	0.98	0.56
Total Accidents per 100,000 Landings	3.22	13.29	7.04	6.38	25.88	12.14	2.80	12.19	6.45
Total Dollar Cost (in 000's)	14,349	81,388	95,738	2,288	11,860	14,148	12,062	69,528	81,590
Average Dollar Cost per Accident	62,936	141,792	119,374	43,165	131,777	98,935	68,923	143,654	123,809
Total Fatalities	68	294	362	13	34	47	55	260	315
Average Fatalities per Accident	0.30	0.51	0.45	0.25	0.38	0.33	0.31	0.54	0.48
Fatal Accidents - Number	27	97	124	6	14	20	21	83	104
Fatal Accidents - Percent	11.84	16.90	15.46	11.32	15.56	13.99	12.00	17.15	15.78
Average Fatalities per Fatal Accidents	2.52	3.03	2.92	2.17	2.43	2.35	2.62	3.13	3.03
Total Injuries (Nonfatal)	124	629	753	20	72	92	104	557	661
Average Injuries per Accident	0.54	1.10	0.94	0.38	0.80	0.64	0.59	1.15	1.00

When the aircraft inventory data listed in Table I are examined, two points become obvious. First, the average number of aircraft operating out of VN during the survey period was much less than the number of aircraft operating elsewhere. In relative terms, only 33.31 percent of the total inventory were stationed in VN as compared to 66.69 percent stationed elsewhere resulting in a VN/US inventory ratio of 0.50 to 1 for all aircraft types. The second point to be gained is that RW aircraft were the predominant aircraft in the Army Aviation inventory. Of the total number of aircraft, 67.87 percent were of the RW type and 32.13 percent of the FW type. For each type of aircraft, the VN/US inventory ratio was less than unity, i.e., 0.25 to 1 for FW and 0.66 to 1 for RW. Accordingly, in terms of average aircraft inventory, the majority of the aircraft operated in US and the majority of the aircraft was of the RW type.

A similar, though smaller, US predominance results when total aircraft flight hours are used as a weighting factor. The data of Table I shows that Army aircraft were flown a total of 3,625,000 hours during the year beginning July 1966 of which 1,681,000 hours were flown in VN and 1,944,000 hours elsewhere. This total is composed of 816,000 hours in FW aircraft (see column 7) and 2,808,000 hours in RW aircraft (see column 10). In all cases, the US hours were more than the VN hours. It should be observed also that the total hours flown in RW aircraft much exceeded those in FW aircraft, even allowing for the fact that the RW inventory was greater than the FW inventory. That is, the over-all RW/FW flying hour ratio was approximately 3.44 to 1 while the RW/FW aircraft inventory ratio was only 2.11 to 1. Similarly, in terms of landings, the utilization of both FW and RW aircraft was greater in the US. As would be expected due to the short-range, multiple-hop missions of helicopters, the total landings of RW aircraft exceeded those of FW aircraft, with the raw RW/FW landing ratio being about 8.67 to 1.

With these background data as reference, it becomes possible to make a weighted interpretation of the raw accident data presented in Table I. Selected excerpts from these data are plotted in Figures 1 and 2. The numerical incidence of all major and minor aircraft accidents, regardless of type or causal factor, is plotted in Figure 1. The cost of these accidents as measured by the number of fatal accidents, number of fatalities, number of nonfatal injuries, and aircraft dollar damage, is outlined in Figures 2A through 2D, respectively.

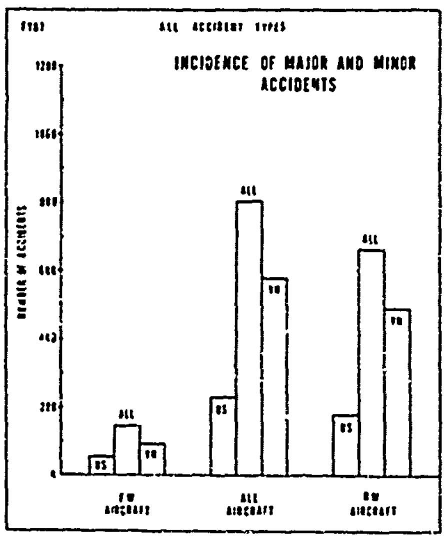


Figure 1
All Accident Types: Total number of major and minor aircraft accidents of all types that occurred in Army Aviation flight operations from July 1966 to July 1967. Total number of FW accidents is shown by the center bar at the left, with the adjacent VN and US bars indicating location of the accidents. Data for RW accidents are at extreme right, with total accidents of both aircraft types summarized in the center. The VN data presented throughout this report pertain to aircraft accidents, not losses due to enemy action, that occurred in Vietnam. Note that though the Table I weighting factor data indicate a greater aircraft utilization in the US, the greater number of accidents occurred in Vietnam.

In terms of the over-all aircraft accident problem, there were a total of 802 accidents, 124 of which were fatal; there resulted 362 fatalities, 753 nonfatal injuries, and a total aircraft damage cost of 95.7 million dollars. The FW aircraft contribution to these totals was 143 accidents (20 of which were fatal), resulting in 47 fatalities, 92 nonfatal injuries, and a total aircraft damage cost of 14.1 million dollars. The RW data show 659 accidents (104 of which were fatal), resulting in 315 fatalities, 661 nonfatal injuries, and a total aircraft damage cost of 81.6 million dollars.

To facilitate the comparison of these data with accident incidence data to be presented for subsequent years, the data sets in Figure 1 have been normalized relative to the total number of flying hours flown by each type of aircraft in both locales and plotted in Figure 3A as the average number of accidents occurring every 100,000 hours. The same normalization with total landings as reference was accomplished for Figure 3B which shows the accident rate for every 100,000 landings. The extent to which the VN accident rate exceeded that occurring elsewhere is shown in Figures 4A and 4B which plot the VN/US accident ratio for the different types of aircraft with equal flying hours and equal landings, respectively, as weighting factors. When an equal number of flying hours was used as reference, the incidence of accidents in VN was 2.18 times greater than the incidence in US for FW aircraft, 3.11 times greater for RW aircraft, and 2.91 times greater for their combined total. For the equal landings data of Figure 4B, the VN/US accident ratio climbed to 4.06 to 1 for FW aircraft, 4.35 to 1 for RW aircraft, and 4.13 to 1 for their total. Thus, without exception, these data show that the magnitude of the accident problem in VN far exceeded that existing elsewhere. This despite the fact that the aircraft inventory, total flight hours, and total landings data indicate that aircraft utilization was greater in the US. The greater accident potential associated with the stresses of a combat-oriented environment is quite obvious.

To show the relationship between accident incidence in RW aircraft and that in FW aircraft, the RW/FW accident ratio for the two locations is plotted in Figures 5A and 5B, with again total hours and total landings, respectively, as normalization factors. In Figure 5A, the RW/FW accident ratio of 1.02 to 1 for accidents occurring in US indicates that the hazard here was about equal for both aircraft types. In VN, however, the incidence of accidents in RW aircraft was about 1.45 times as great as that in FW aircraft with equal flying hours as reference. However, when equal landings were used as reference, as is done in Figure 5B, these data showed a RW/FW accident ratio less than unity, indicating a higher incidence for FW accidents. It may also be observed from the data of Figure 5B that the RW/FW accident ratio was about the same for accidents occurring in VN as for those occurring elsewhere.

PILOT-ERROR ACCIDENTS

In this section, incidence and cost data are presented for all accidents that were classified by USABAAR as involving one or more pilot-error causal factors. It should be observed that this classification does not imply that pilot error was the

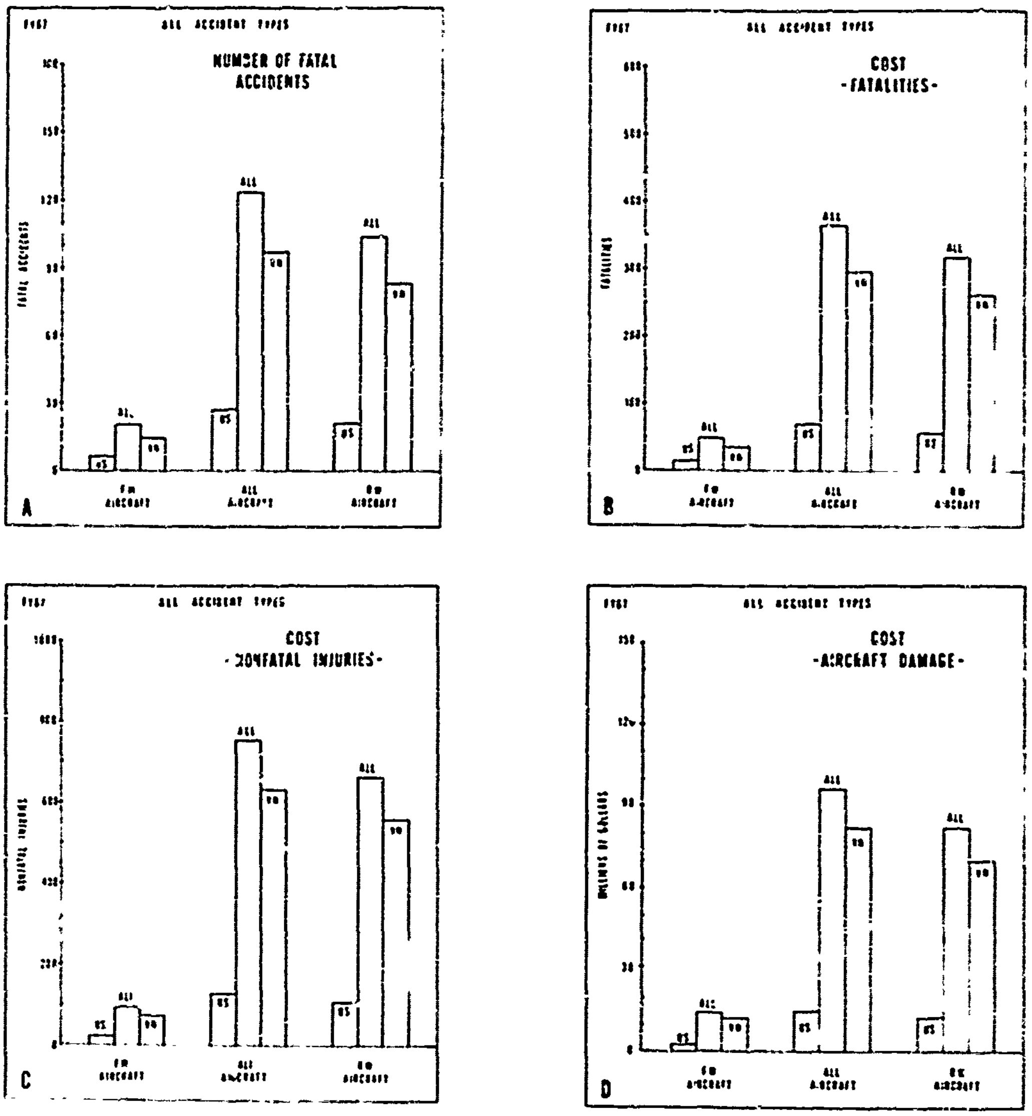


Figure 2
All Accident Types: Total number of fatal accidents (A), total number of fatalities (B), total number of nonfatal injuries (C), and total dollar cost of resulting aircraft damage (D) for both RW and FW aircraft and for both VN and US locations.

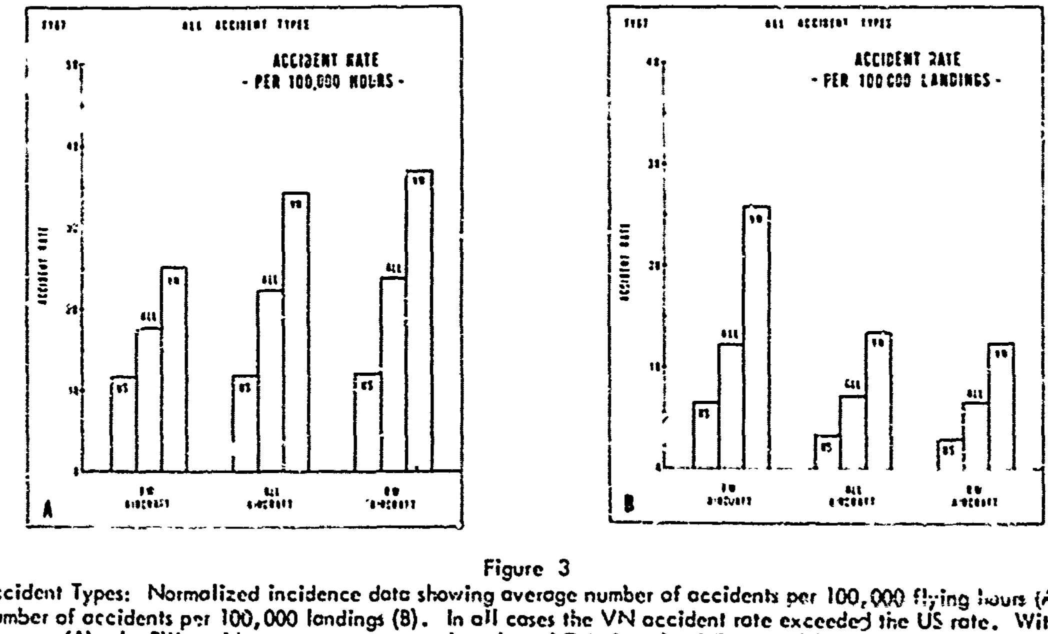


Figure 3
All Accident Types: Normalized incidence data showing average number of accidents per 100,000 flying hours (A) and average number of accidents per 100,000 landings (B). In all cases the VN accident rate exceeded the US rate. With total hours as reference (A), the RW accident rate was greater than that of FW aircraft. When total landings were used (B), the RW accident rate fell as would be expected from the short-range, multi-hop missions typically performed by helicopters.

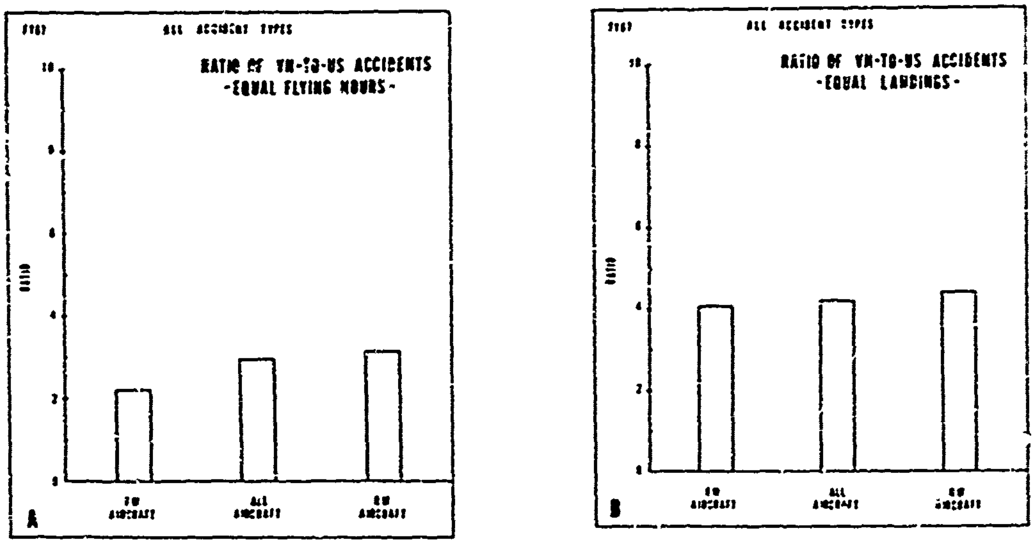


Figure 4
All Accident Types: Normalized ratio of accidents occurring in VN to accidents occurring in US based on equal flying hours (A) and equal landings (B) for both types of aircraft. When hours served as the normalization reference (A) the probability of a FW accident occurring in VN was over twice as great as accidents occurring elsewhere. A similar but larger probability was present for RW accidents that occurred in VN. The normalized landing data (B) indicate that the probability of either a FW or RW accident occurring in VN was at least four times as great as the probability of an accident elsewhere.

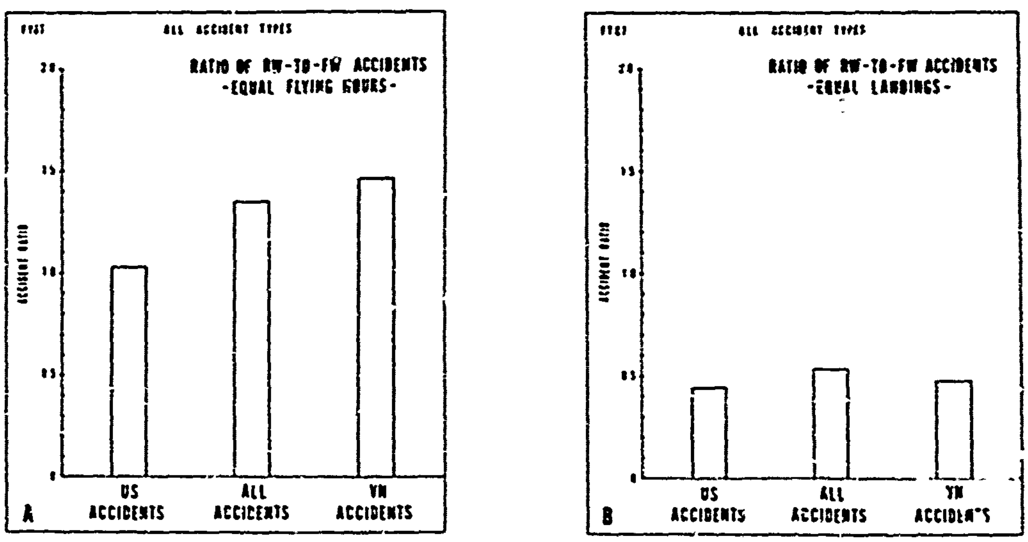


Figure 5
All Accident Types: Normalized ratio of accidents occurring in RW aircraft to accidents occurring in FW aircraft based on equal flying hours (A) and equal landings (B) for both locations. When equal hours served as a reference (A), the probability of an accident occurring in the US was about the same for both aircraft types. In VN, the RW accident rate was almost 1.5 times as great as the FW accident rate. When equal landings were used as a reference (B) the probability of an accident occurring in a RW aircraft was less than that for FW aircraft. This ratio is about the same whether the accident occurred in VN or elsewhere.

only, or even the primary, accident causal factor. That is, this grouping includes all accidents involving one or more pilot errors even though, for example, material failure, maintenance shortcomings, or poor facilities may also have contributed to the cause of the accident. A further point, by definition, is that these pilot-error accidents are a subgroup of the all-accident statistics discussed in the previous section.

Incidence and cost data for pilot-error accidents in this period are presented in Table II and Figures 6 and 7. The incidence data of Figure 6 show that there was a total of 552 major and minor accidents involving pilot error; of this total, 75 were fatal accidents. The over-all cost was 189 fatalities, 525 nonfatal injuries, and $60,386,000 aircraft damage. The FW contribution to this total was 106 accidents (13 of which were fatal), resulting in 35 fatalities, 69 nonfatal injuries, and $9,393,000 aircraft damage. For RW aircraft, there were 446 accidents (61 of which were fatal), resulting in 154 fatalities, 456 nonfatal injuries, and $50,993,000 aircraft damage.

As with the all-accident data, normalized pilot-error accident rate for FW aircraft as well as for RW aircraft was greater in VN, whether one used total flying hours or total landings as reference. Indeed, for RW aircraft, the VN-based rate of 23.58 accidents per 100,000 hours was 2.61 times greater than the US-based rate of 9.02 accidents per 100,000 hours.

Likewise for landings, the VN rate of 7.86 accidents per 100,000 accidents was, compared to the 2.14 US rate, 3.67 times greater.

TABLE II

ACCIDENT SUMMARY - PILOT ERROR ACCIDENTS ONLY
JULY 1966 TO JULY 1967

ACCIDENT INDEX	ALL AIRCRAFT			FIXED WING AIRCRAFT			ROTARY WING AIRCRAFT		
	Accidents			Accidents			Accidents		
	U.S.	Vietnam	All	U.S.	Vietnam	All	U.S.	Vietnam	All
Major Accidents	166	344	510	45	56	101	121	288	409
Minor Accidents	17	25	42	4	1	5	13	24	37
Total Accidents	183	369	552	49	57	106	134	312	446
Total Dollar Cost (in 000's)	10,846	49,540	60,386	2,199	7,194	9,393	8,647	42,346	50,993
Average Dollar Cost/Accident	59,268	134,256	109,396	44,870	126,217	88,613	64,533	135,724	114,335
Total Fatalities	35	154	189	13	22	35	22	132	154
Average Fatalities/Accident	0.19	0.42	0.34	0.27	0.39	0.33	0.16	0.42	0.35
Fatal Accidents - Number	18	57	75	6	7	13	11	50	61
Fatal Accidents - Percent	9.84	15.45	13.59	12.24	12.28	12.26	8.21	16.03	13.68
Average Fatalities/Fatal Accident	1.94	2.70	2.52	2.17	3.14	2.69	2.00	2.64	2.52
Total Injuries (Nonfatal)	102	423	525	19	50	69	83	373	456
Average Injuries/Accident	0.56	1.15	0.95	0.39	0.88	0.65	0.62	1.20	1.02

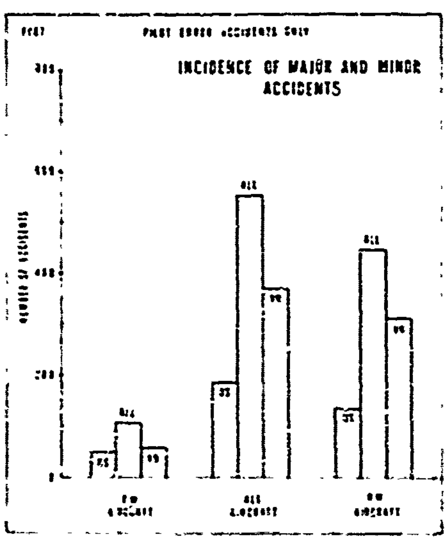


Figure 6
Pilot-Error Accident Types: Total number of major and minor accidents that were classified by USABAAR as involving one or more pilot-error factors. As with the Figure 1 "All Accident Type" incidence data, the number of pilot-error accidents occurring in RW aircraft operating out of VN considerably exceeded those occurring elsewhere. However, for FW aircraft, the number of pilot-error accidents that occurred in VN only slightly exceeded those that occurred in US.

ORIENTATION-ERROR ACCIDENTS ONLY

This section summarizes the incidence and cost of all orientation-error type accidents detected in our review of the USABAAR accident files. As detailed with selected qualifications in the procedure section of this report, this listing includes all accidents arising from an incorrect control or power action taken by a pilot due to his incorrect perception of the true motion or attitude of his aircraft. The reader should recognize that the orientation-error accidents discussed herein are a subgroup of the pilot-error accident statistics presented in the previous section.

The main elements of the orientation-error statistics are summarized in Table III. The pertinent incidence and cost data are outlined in Figures 8 and 9.

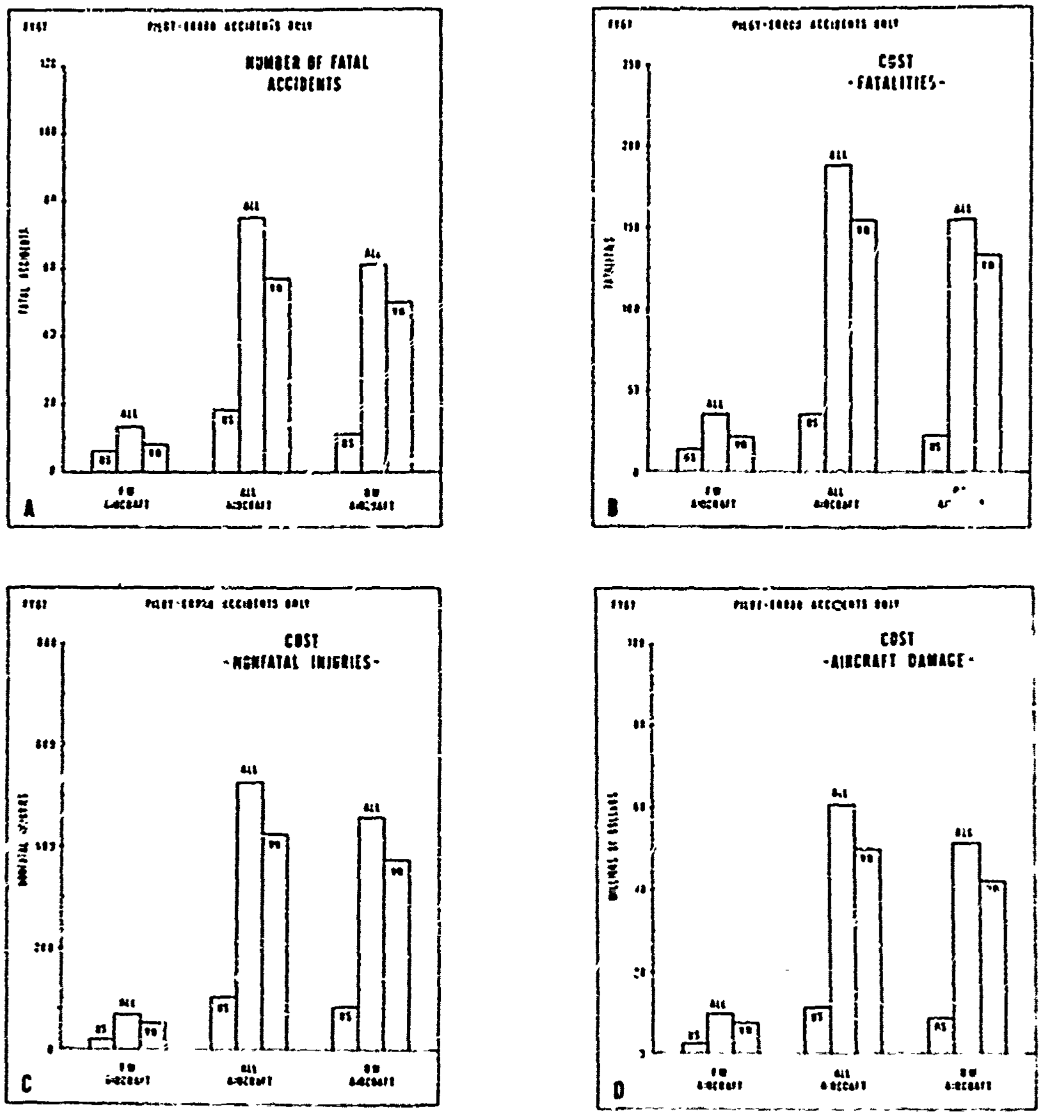


Figure 7

Pilot-Error Accident Types: Total number of fatal accidents (A), total number of fatalities (B), total number of nonfatal injuries (C), and total dollar cost of resulting aircraft damage (D) for both aircraft types and for both locations.

TABLE III
ACCIDENT SUMMARY - ORIENTATION ERROR ACCIDENTS ONLY
JULY 1966 TO JULY 1967

ACCIDENT INDEX	ALL AIRCRAFT Accidents U.S.	Vietnam	All	FIXED WING AIRCRAFT Accidents U.S.	Vietnam	All	ROTARY WING AIRCRAFT Accidents U.S.	Vietnam	All
Major Accidents	9	41	50	0	1	1	9	40	49
Minor Accidents	0	7	7	0	1	1	0	6	6
Total Accidents	9	48	57	0	2	2	9	46	55
Total Dollar Cost (in 000's)	1,360	8,784	10,144	0	27	27	1,360	8,757	10,117
Average Dollar Cost/Accident	151,094	183,004	177,966	---	13,594	13,594	151,094	190,370	183,943
Total Fatalities	3	42	45	0	1	1	3	41	44
Average Fatalities/Accident	0.33	0.88	0.79	---	0.50	0.50	0.33	0.89	0.80
Fatal Accidents - Number	1	19	19	0	1	1	1	17	18
Fatal Accidents - Percent	11.11	37.50	33.33	---	50.00	50.00	11.11	36.96	32.73
Average Fatalities/Fatal Accident	3.00	2.33	2.37	---	1.00	1.00	3.00	2.41	2.44
Total Injuries (Nonfatal)	13	92	105	0	1	1	13	91	104
Average Injuries/Accident	1.44	1.92	1.84	---	0.50	0.50	1.44	1.98	1.89

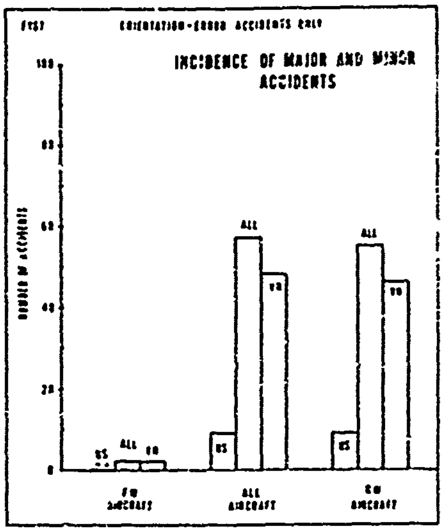


Figure 8
Orientation-Error Accident Types: Total number of major and minor orientation-error accidents located in the search of the USABAAR master accident files for the period July 1966 to July 1967. Note that only two FW accidents, both of which occurred in VN, were detected in this search.

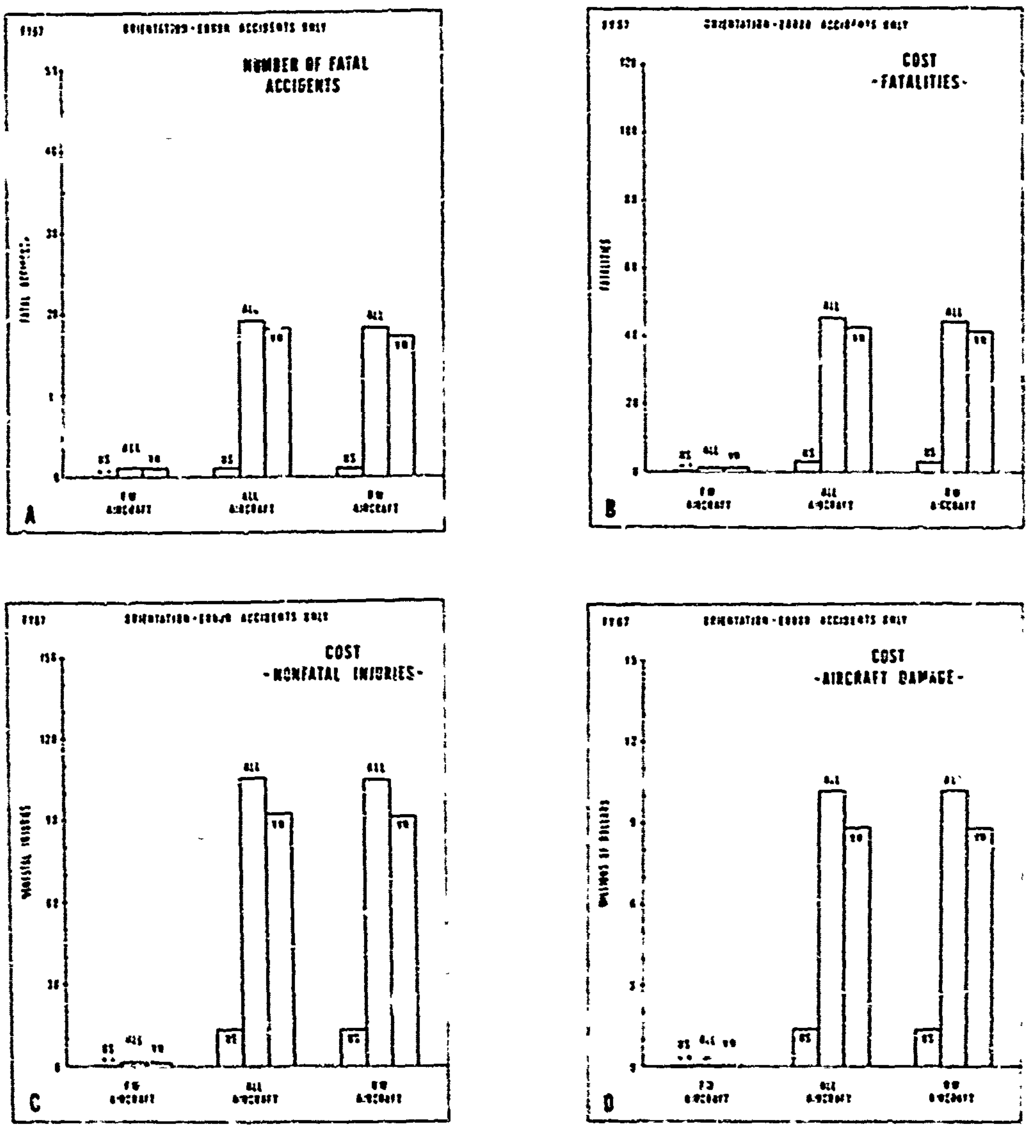


Figure 9
Orientation-Error Accident Types: Total number of fatal accidents (A), total number of fatalities (B), total number of non-fatal injuries (C), and total dollar cost of resulting aircraft damage (D) for both aircraft types and for both locations. Note that there was only one fatal FW accident (A).

These data show that there were a total of 57 major and minor orientation-error accidents (19 of which were fatal), resulting in 45 fatalities, 105 nonfatal injuries, and an aircraft damage cost of $10,144,000. The FW contribution was extremely small with only one minor accident and one major fatal accident occurring; the over-all cost here was one fatality, one nonfatal injury, and a total dollar damage of $27,000. It is obvious that with such a low incidence (n) for FW orientation-error accidents, conclusions to be drawn as to RW/FW or US/VN accident incidence and cost must await the acquisition of further FW data in this longitudinal study. We have attempted to alert the reader to this low incidence in the various related graphs by listing the small n value next to the FW data. For RW aircraft, there were a total of 55 major and minor orientation-error accidents (18 of which were fatal), resulting in 44 fatalities, 104 nonfatal injuries, and a total aircraft dollar damage of $10,117,000. Thus the majority of the orientation-error accidents involving Army Aviation aircraft occurred in RW aircraft during this period. As indicated by the RW data, the incidence and cost of accidents occurring in VN were both considerably greater than for accidents occurring elsewhere. This is particularly noticeable in the 17.00 to 1 VN/US fatal accident ratio, the 13.67 to 1 VN/US total fatality ratio, the 7.00 to 1 VN/US total injury ratio, and the 6.44 to 1 VN/US total dollar cost ratio.

The normalized rates for hours of exposure were 3.48 and 0.61 accidents per 100,000 hours for VN- and US-based aircraft, respectively. In terms of landings, the rates were 1.16 and 0.14 accidents per 100,000 landings for VN- and US-based aircraft, respectively. Thus for orientation-error accidents the VN-to-US ratios become 5.70 and 8.26 for hours and landings, respectively, a substantially more adverse rating for the combat environment.

For general reference, a breakdown of the 50 major and 7 minor orientation-error accidents by aircraft types is as follows. The FW accidents included one minor accident in an O1-D and one major accident in an O1-E. Bad weather during a night landing was involved in the O1-D accident. The O1-E accident involved a daytime flight in good visibility when a loss of depth perception resulted during a diving, low-level gunnery run over water. The UH-1 aircraft accounted for 44 of the 49 major RW accidents and 6 of the minor accidents. The remainder of the major RW accidents were accounted for by two type CH-47A aircraft, one type CH-21 aircraft, one type OH-13S aircraft, and one type TH-55 aircraft. Of these five accidents, all resulted in aircraft strikes except for the TH-55 accident. One CH-47A accident occurred at night when the aircraft flew into a low-level cloud bank during a 180-degree left turn while making a landing go-around. The second CH-47A accident involved a medical evacuation mission requiring a night takeoff into IFR weather, with spatial orientation difficulties arising when aircraft searchlights reflected on low cloud cover. The CH-21 accident occurred during an IFR takeoff through thick ground smoke. In the case of the OH-13S accident, ground haze and mist during a night flight through a mountain pass resulted in aircraft control problems. The TH-55A accident resulted when the pilot assumed the sloped surface of a mountain was horizontal and controlled his aircraft accordingly.

It is quite apparent that the majority of the RW accidents involved the Army workhorse, the UH-1 "Huey." The high incidence here is due only to the UH-1 being the predominant RW aircraft in the Army inventory. Because of the many advantages to be gained from a study involving only one basic aircraft type, orientation-error accidents that occurred in the UH-1 are undergoing detailed review relative to the various pilot, aircraft, and environmental factors involved in such accidents and will be reported separately.

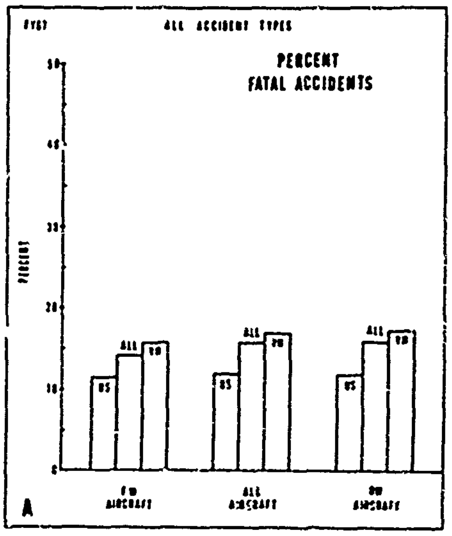
COMPARATIVE INCIDENCE AND COST OF ORIENTATION-ERROR ACCIDENTS

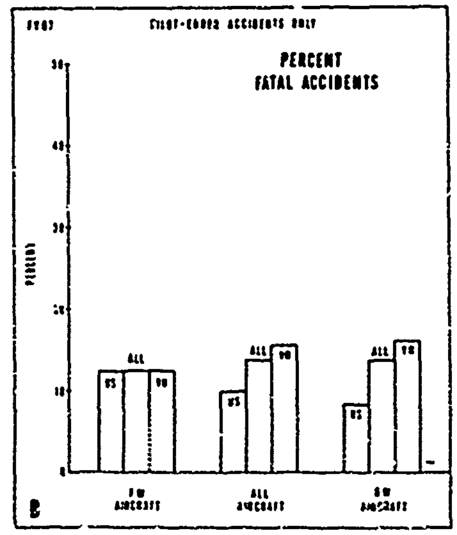
The arrangement of the data presented in the previous sections was selected to differentiate the actual incidence and cost of all accidents, pilot-error accidents, and orientation-error accidents. In this section, selected incidence and cost data are expressed in percentage figures with the objective of gaining some insight into the relative contribution of orientation-error accidents to the over-all accident problem.

In Figure 10 the percent incidence of fatal accidents is described for all accident types, pilot-error accident types, and orientation-error accident types. The Figure 10A data show that for FW aircraft 13.99 percent of all FW accidents, regardless of accident cause or type, were fatal, with the incidence in VN being about 1.37 times greater than in US. The RW data indicate that 15.78 percent of all RW accidents were fatal, with the VN incidence 1.43 times greater than the US incidence. In effect, considering all accidents, little difference exists in FW and RW fatal accident incidence within a given location. Considering both aircraft types together, the totalized data of Figure 10A indicate 15.46 percent of all accidents were fatal.

When one evaluates only those accidents of the above group that involved pilot error, the relative incidence of fatal accidents is less, as indicated in Figure 10B. Here, the fatal accident incidence was 12.26 percent for FW aircraft, 13.68 percent for RW aircraft, and 13.59 percent for the combined sum of FW and RW pilot-error accidents. The VN US fatal accident incidence ratio for RW aircraft was 1.95 to 1. For FW aircraft, however, the VN and US incidence ratio was about the same. A comparison of Figure 10A and 10B would indicate that during the July 1966 to July 1967 period, the probability of a fatal accident occurring when pilot error was involved was slightly less than the probability of a fatal accident occurring when pilot error was not involved.

For orientation-error accidents, however, the probability of a fatal accident was much higher, as shown in Figure 10C. Again, the reader is cautioned to remember the low incidence of FW accidents for this period. The total number of FW accidents, n=2, of which one was fatal, accounts for the 50 percent fatal accident incidence data of this figure. (The FW data of Figure 10C are drawn in dashed outline to ensure recognition of this low incidence.) Thus in these data, the relative incidence and cost of orientation-error accidents derived almost exclusively from RW accidents. In the remaining orientation-error figures then, the "All Aircraft" data will, in essence, be identical to the "RW Aircraft" data. The percent incidence of fatal accidents when orientation error was involved rose to 33.33 percent with the incidence in VN being considerably greater than that in US; in fact, 3.38 times as great.





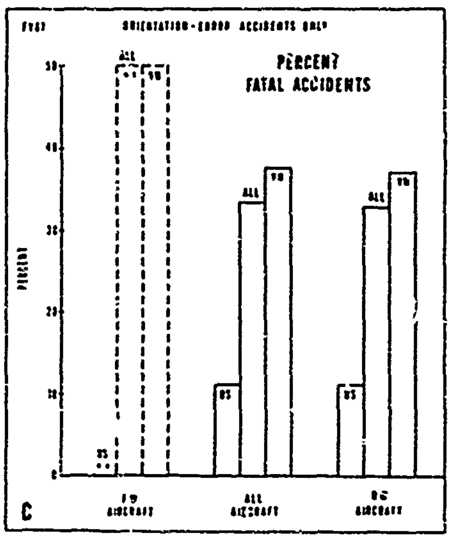


Figure 10

Comparative incidence of fatal accidents expressed as the percent of the total number of accidents within the "All Accident Type" (A), "Pilot-Error Accident Type" (B), and "Orientation-Error Accident Type" (C) classifications that resulted in one or more fatalities. Comparison of the totalized RW and FW data of (A) with their (B) counterpart, indicates that the probability of a fatal accident occurring when pilot-error was involved was slightly less than when pilot-error was not present. Note that orientation-error accidents, a specific subgroup of pilot-error accidents, had a significantly higher percentage of fatal accidents. In (C) the FW data are drawn in dashed outline to caution the reader of the very few cases involved; i.e., two FW accidents with one being fatal.

Similar comparisons for the three classes of accidents are made in Figure 11 for the average number of fatalities per fatal accident. Again the cost of pilot-error accident types was less than the cost of all accident types, with the VN cost exceeding the US cost. However, for orientation-error accidents the average number of fatalities per fatal accident was slightly less than that of the pilot-error accident types while the US cost, in this case, exceeded the VN cost. The same format is used in Figure 12 which depicts the average number of nonfatal injuries that occurred per accident. The all-accident type and the pilot-error accident type data were about the same. For the orientation-error accident data, however, the average number of injuries per accident was considerably higher. The higher average aircraft dollar cost of orientation-error accidents also exceeded the average cost of the other accident types, as illustrated in Figure 13.

Figures 14 through 17 illustrate the relative contribution of orientation-error accidents in all aircraft types to selected incidence and cost data as a given percentage of corresponding statistics for both "all accident types" and "pilot-error accident types." In Figure 14, orientation-error accidents can be seen to represent 7.11 percent of all accidents that occurred during this year and 10.33 percent of all pilot-error accidents. When one considers the number of fatal accidents that occurred in the two accident groups, as is done in Figure 15, orientation-error fatal accidents represent 15.32 percent of all fatal accidents and 25.33 percent of all fatal pilot-error accidents. In terms of fatalities, orientation-error accidents resulted in 12.43 percent of the total number and 23.81 percent of those occurring in pilot-error accidents, as indicated in Figure 16. Lastly, orientation-error accidents accounted for over 10.59 percent of the total cost of all accidents and 16.80 percent of the cost of all pilot-error accidents, as shown in Figure 17. The percentage contribution of orientation-error accidents to the "all accident" cost was about the same for VN as elsewhere. However, for all other data presented in Figures 14 through 17, the magnitude of the orientation-error problem in VN was considerably greater than the magnitude of the problem elsewhere.

At this time, no attempt will be made to discuss further these findings or to draw any conclusions as to their over-all significance. Since corresponding data are under preparation for subsequent years, the full significance of the present data will depend upon whether this longitudinal analysis does or does not establish the presence of consistencies or trends in the accident experiences. Moreover, it is the function of this element of the longitudinal study only to provide quantitative data; the actual evaluation of the accident data in terms of effect on the military mission must remain with those responsible for the direction of military aviation operations.

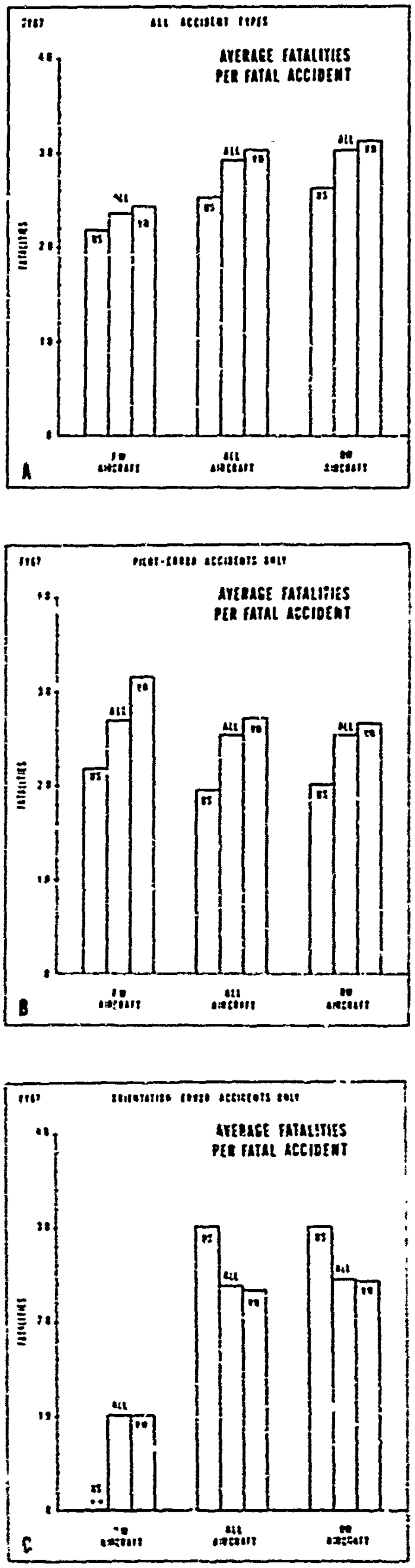


Figure 11
Average number of fatalities per fatal accident occurring within the "All Accident Type" (A), "Pilot-Error Accident Type" (B), and "Orientation-Error Accident Type" (C) classifications. Note that there were no fatal orientation-error accidents in FW aircraft.

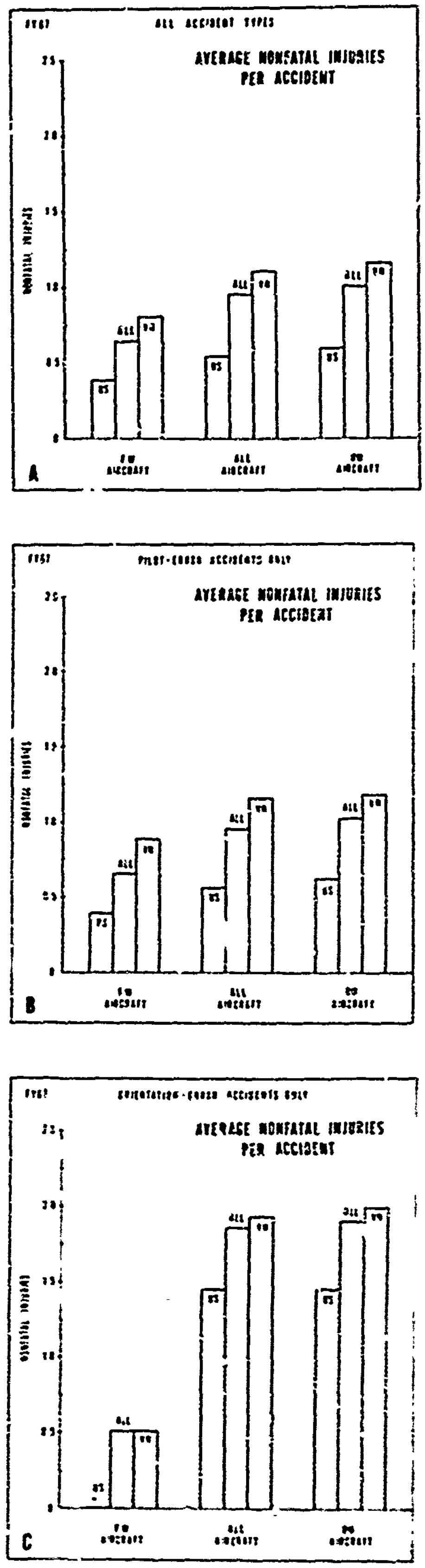
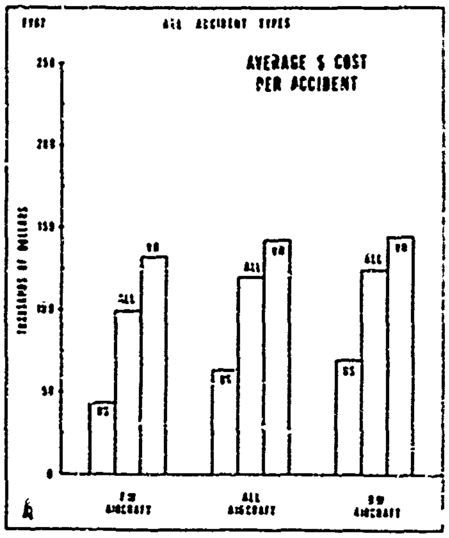
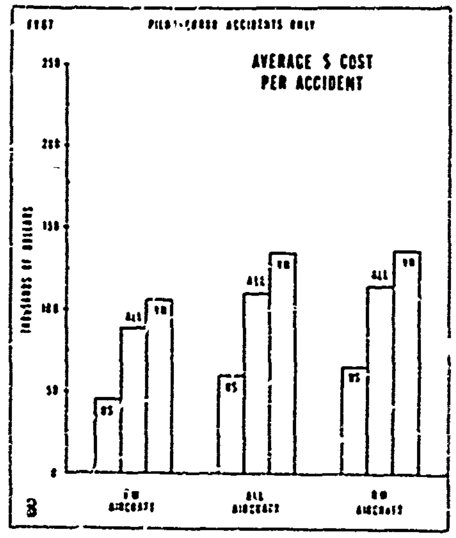


Figure 12
Average number of nonfatal injuries per accident occurring within the "All Accident Type" (A), "Pilot-Error Accident Type" (B), and "Orientation-Error Accident Type" (C) classifications. The orientation-error accidents had the greatest injury rate.





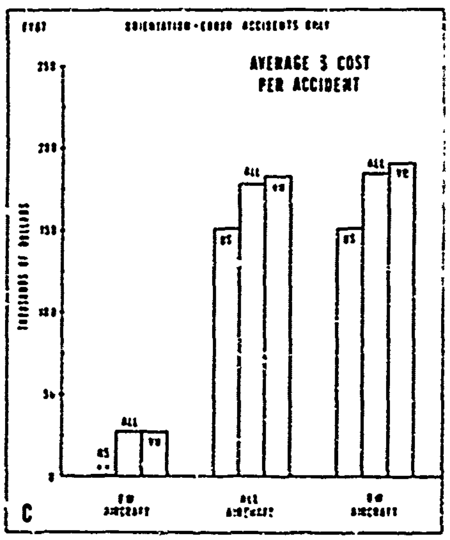


Figure 13
Average aircraft dollar damage per accident occurring within the "All Accident Type" (A), "Pilot-Error Accident Type" (B), and "Orientation-Error Accident Type" (C) classifications. Orientation-error accidents produced the greatest dollar damage per accident.

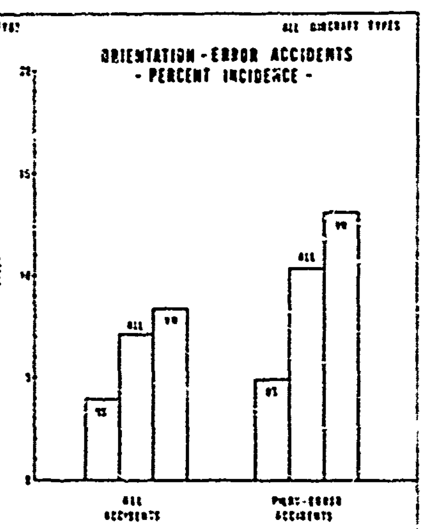


Figure 14
Percent contribution of all orientation-error accidents to the total number of accidents occurring within the "All" Accident Type" and the "Pilot-Error Accident Type" classifications.

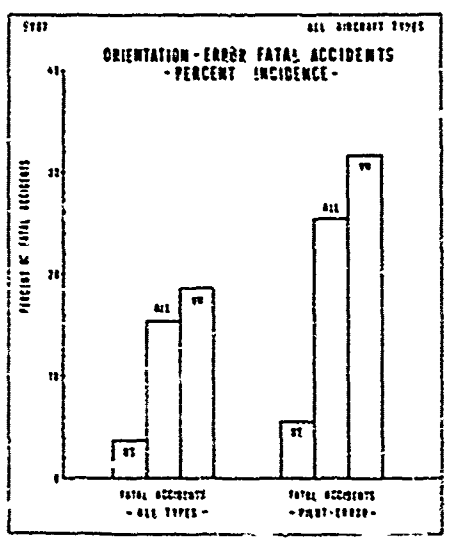


Figure 15
Percent contribution of all fatal orientation-error accidents to the total number of fatal accidents occurring within the "All Accident Type" and the "Pilot-Error Accident Type" classifications.

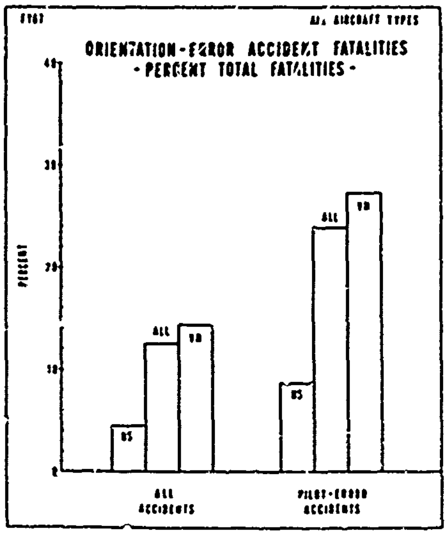


Figure 16
Percent contribution of all orientation-error accident fatalities to the total number of fatalities occurring within the "All Accident Type" and the "Pilot-Error Accident Type" classifications.

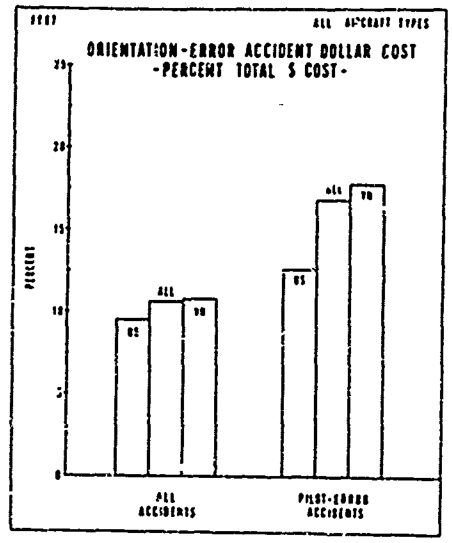


Figure 17
Percent contribution of the dollar cost of all orientation-error accidents to the total cost of all accidents occurring within the "All Accident Type" and the "Pilot-Error Accident Type" classifications.

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DISCUSSION

CLARK. Your principal concern has been with accidents caused by disorientation, but would you care to comment on the reduction of operational efficiency which might be produced by disorientation?

NIVEN. We have indications from data, yet to be reported, that disorientation interferes with mission effectiveness because a disorientation error accident occurs before the mission objective is achieved.

BENSON. Both you and Wing Commander Lotting have been concerned with analysing accident reports. To what extent do you regard the information, gathered by others, reliable? Do you consider that the real cause or causes of the accident are adequately described in the documents upon which your analysis is based?

NIVEN. To use Dr Clark's phrase - the data are noisy. Our initial approach was one of confidence but as the investigation progressed it was apparent that the information we required had not always been obtained because orientation error had not been in the mind of the investigators. As a result of our enquiry modification to the accident investigation questionnaire will be made.

BAILEY. Army helicopters are completely fitted with flight instruments and qualified for instrument flight rule control. Some of the trainers eg H-13 and TH-55 are not completely instrumented, but the UH-1 aircraft in this study are fully instrumented with flight instruments for both pilot and co-pilot. It is important to know that all helicopter instrumentation is merely antiquated fixed-wing instruments transferred to rotary winged aircraft. This makes the task of instrument flight in a more unstable aircraft considerably more difficult and hazardous than in fixed-wing aircraft.

NIVEN. Thank you for qualifying this point.

GILSON. Would you attribute the greater accident rate in helicopters to the basic instability of rotary-wing versus fixed-winged aircraft where dangerous attitudes are attained with briefer periods of inattention?

NIVEN. This is undoubtedly one of the factors, amongst many, contributing to orientation error accidents in helicopters.

CLARK. Were accidents in which the aircraft came to a hover in dust, with resultant loss of control, included in the presented statistics?

NIVEN. Yes.

DISORIENTATION, "FACT AND FANCY"

by

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SUMMARY

The results of a survey of 2,000 naval aviators concerning their experience with disorientation during various flight conditions is presented. An analysis of all naval flight accidents for calendar year 1969, in which a disorientation incident contributed to the accident is presented.

It is shown that the majority of accidents coded "Disorientation" as a causal factor, were, in fact, erroneously coded. Of the 48 accidents so coded, only seven provided adequate evidence that disorientation was a factor in the accident.

Major conclusions drawn in this report include: (1) 96% of all aviators experience disorientation at some time during their flying career (2) the majority of accidents listing disorientation as a factor either are erroneously coded or the reports fail to provide sufficient evidence to validate a diagnosis of disorientation (3) the probability of the true incidence of disorientation caused accidents is very small (0.9%) for calendar year 1969 (4) most incidents of pilot disorientation occur during periods of reduced visibility.

While vestibular inputs may play a part in producing disorientation, many disorientation incidents take place when the vestibular system is relatively unperturbed. It is rare to find disorientation without reduced visual conditions. Thus, the hypothesis is put forth that the primary sensory system responsible for disorientation is the visual system.

The need for further research in the visual system is stressed, along with the need for new emphasis in pilot indoctrination concerning the effects of reduced visibility.

INTRODUCTION

Disorientation and vertigo are terms that have been used to recognize a syndrome which affects most pilots at some time during their flying career. Further, disorientation and vertigo are probably two of the least understood and the most misused terms used today to describe causes of aviation accidents.

The three terms disorientation, vertigo and dizziness are frequently used interchangeably to describe a wide variety of symptoms such as false sensations of angular acceleration, of linear acceleration or of a tilt sensation.

Medically the word vertigo is used to describe the sensation of the world revolving around the patient (objective vertigo) or of the patient himself revolving in space (subjective vertigo). The Dorland Medical Dictionary goes on to state that the term is sometimes erroneously used as a synonym for dizziness.

Since true vertigo rarely if ever occurs in aviation without another disease process present, it is recommended that this term not be used as a descriptive term to describe accidents, unless true objective or subjective dizziness is present.

Disorientation on the other hand has several meanings. The first one relates to time, place or identity. While this definition may apply to many people, both on the ground and in the air, it is generally reserved for those with either a psychiatric disorder or organic brain damage which interferes with their thought processes. The second generally accepted usage of the term disorientation denotes the loss of proper geographical bearings. Again this does not apply exactly to the aviation situation, since the connotation could mean something more than being "lost." In aviation one may not only lose his sense of direction but also his sense of spatial relationship with respect to the earth. Presently there have been reports published which use the term "orientation-error," to describe periods in which the pilot was considered to perceive a motion and attitude of his aircraft which differed from the true motion and attitude. This can simply be referred to as "spatial disorientation."[1]

Having defined spatial disorientation as perception of motion and attitude which differs from the true; just how often does it exist in naval aviation today, to what degree has it been a hazard (i.e., cause of accidents) and if it is significant hazard, how can it be prevented. These questions have been asked many times and continue to be asked even today.

PROCEDURE

In 1970 the Bureau of Medicine and Surgery had a project to identify medical research needed to support naval aviation. Two of the methods used to identify this requirement were: a review of accident data from the Naval Safety Center for the calendar year 1969 and a questionnaire sent to 3,000 active duty naval aviators. Of these 3,000 questionnaires over 2,000 have been returned to the Bureau of Medicine and Surgery. The questionnaire was divided into two sections, one concerning spatial disorientation and one

concerning general medical problems. Only the former section will be discussed in this paper.

The spatial disorientation questionnaire was divided into five parts. The first part contained general information questions as to rank, designator, number of flight hours, types of aircraft flown and the questions:

(1) Have you ever experienced disorientation while piloting U. S. Navy aircraft?

never______once_____occasionally_____frequently______

(2) If the answer to the above question is "yes" did the disorientation incident hazard you or your aircraft?

yes_______no______

The second part considered the various flight conditions which contributed to the disorientation incidents reported in the first part, such as IFR conditions, VFR (day and night), turbulence and broken clouds. The third part related to the pilot's subjective physical condition at the time of disorientation such as illness, fatigue, hangover, headache, hypoxia, drug reactions, etc. The fourth part concerned visible phenomena such as starlight, surface lights, passing aircraft lights, flicker phenomenon, etc. The fifth and last part inquired about aircraft maneuvers and spatial orientation of the aircraft at the time of the disorientation incident. These included: catapult take off, level flight, climb, glide, dive, rolls, high G (two or more) turns less than 20° of bank or more than 20° of bank and formation flying (lead or wingman).

To simplify answering by each pilot, all questions (except for information concerning rank, flight hours and type of aircraft flown) could be completed by checking an appropriate box.

RESULTS

The results of the questionnaire are tabulated below. The first two questions (Table 1) concerned the total experience with disorientation and whether or not the pilot considered it to be a hazard.

TABLE 1

1. Have you ever experienced disorientation while piloting a Navy aircraft?

Never	68	3.4%
Once	120	6.0%
Occasionally	1584	79.2%
Frequently	214	10.7%
No response	14	0.7%
TOTAL	2000	100%

2. If the answer to the above question is "yes" did the disorientation condition hazard you or your aircraft?

Yes	752	37.6%
No	1128	56.4%
No response	52	2.6%
Not applicable	68	3.4%
TOTAL	2000	100%

Table 2 lists the various flight conditions which contributed to disorientation incidents as well as the pilot's subject condition at the time.

TABLE 2

FLIGHT CONDITIONS WHICH CONTRIBUTED TO THE DISORIENTATION INCIDENTS

	(1) No answer		(2) Never		(3) Once		(4) Occasionally		(5) Frequently		Total of (4) & (5)
	#	%	#	%	#	%	#	%	#	%	%
IFR	134	6.7	148	7.4	202	10.1	1208	60.4	242	12.1	72.5
VFR Day	226	11.3	1530	76.5	68	3.4	94	4.7	14	0.7	5.4
VFR Night	268	13.4	1208	60.4	188	9.4	242	12.1	26	1.3	13.4
Turbulence light	296	14.8	1342	67.1	94	4.7	174	8.7	26	1.3	10.0
Turbulence severe	296	14.8	966	48.3	348	17.4	202	10.1	120	6.0	16.1

TABLE 2 (CON'T)

	(1) No answer #	%	(2) Never #	%	(3) Once #	%	(4) Occasionally #	%	(5) Frequently #	%	Total of (4) & (5) %
Severe fatigue	212	10.7	1034	51.7	214	10.7	430	21.5	40	2.0	23.5
Lack of sleep	188	9.4	818	40.9	236	12.0	644	32.2	26	1.3	33.5
Heat stress	214	10.7	1328	66.4	108	5.4	264	13.4	14	0.7	14.1
Discomfort of per. equip.	228	11.4	1046	52.3	134	6.7	430	21.5	94	4.7	26.2
Headache	214	10.7	1342	67.1	174	8.7	202	10.1	0	—	10.1
Hypoxia	228	11.4	1476	73.8	188	9.4	40	2.0	0	—	2.0
Drugs	242	12.1	1624	81.2	40	2.0	26	1.3	0	—	1.3
Hangover	228	11.4	1074	43.4	268	13.4	322	16.1	40	2.0	18.1
Single light on surface	226	11.3	832	41.6	282	14.1	484	24.2	108	5.4	29.6
Single star	242	12.1	1020	51.0	242	12.1	402	20.1	26	1.3	21.4
General stars	186	9.3	954	47.7	256	12.8	496	24.1	40	2.0	26.1
Carrier deck lights	228	11.4	1262	63.1	134	6.7	308	15.4	0	—	15.4
*MLS lights	228	11.4	1478	73.9	108	5.4	120	6.0	0	—	6.0
Passing aircraft lights	160	8.0	106	50.3	268	13.4	484	24.2	14	0.7	24.9
Reflections from windshield	174	8.7	806	40.3	214	10.7	630	31.5	108	5.4	36.9
Strobing field lights	214	10.7	1490	74.5	94	4.7	134	6.7	0	—	6.7
Tracers passing	252	12.6	1370	68.5	148	7.4	162	8.1	0	—	8.1
Flicker phenomenon	270	13.5	1328	66.4	80	4.0	228	11.4	26	1.3	12.7
Take off (catapult)	268	13.4	966	48.3	214	10.7	416	20.8	68	3.4	24.2
Take off (field)	218	10.8	1234	61.7	134	6.7	322	16.1	26	1.3	17.4
Level flight	106	5.3	832	41.6	228	11.4	698	34.9	68	3.4	38.3
Climb	200	10.0	712	35.6	242	12.1	724	36.4	54	2.7	39.1
Glide	242	12.1	912	45.6	108	5.4	590	29.5	80	4.0	33.5
Dive	134	6.7	954	47.7	228	11.4	536	26.8	80	4.0	30.8
Roll	242	12.1	846	42.3	174	8.7	550	27.5	120	6.0	33.5
High G's (<2)	202	10.1	1182	59.1	148	7.4	308	15.4	80	4.0	19.4
Turn >20° bank	120	6.0	618	30.9	228	11.4	858	42.9	108	5.4	48.3
Turn <20° bank	190	9.5	456	22.8	228	11.4	978	48.9	80	4.0	52.9
Formation lead	256	12.8	1074	53.7	188	9.4	376	18.8	40	2.0	20.8
Formation wing	134	6.7	346	17.4	228	11.4	886	44.3	336	16.8	61.1

*MLS - Mirror Landing System

Table 3 presents data acquired from the Naval Safety Center for the calendar year 1969. A computer print out was analyzed for all accidents listed as having vertigo/disorientation as a causal or contributing factor. Of the 48 accidents only seven were identified in which a definite, positive statement was made as to the occurrence of disorientation. In the remainder, either there was absolutely no evidence to indicate disorientation as a possible factor or it was theorized that disorientation was involved.

TABLE 3

AIRCRAFT ACCIDENTS - CALENDAR YEAR 69

Total Accidents	712	
Disorientation/Vertigo coded accidents	48	6.75%
Accidents with adequate data to indicate disorientation	7	0.98%

In evaluating the 2,000 questionnaires returned to the Bureau, it was noted that many pilots did not answer questions as to flight conditions under which disorientation occurred. This is due possibly to the fact that their answer to question number 1 in Table 1 was "never." These omissions were not tabulated as "never" replies to the question of flight conditions which contributed to disorientation. They were tabulated as "no response" even though it can be assumed to be a "never" answer in accordance with the instruction given with each questionnaire.

In 1956 Clark and Graybiel[2] interviewed 137 jet pilots and found that 96% of the pilots had experienced vertigo in jets and that the nature of vertigo was essentially the same as found in propeller aircraft. In our survey of 2,000 aviators 95.9% stated that they had experienced spatial disorientation at least once--a remarkable agreement between these two studies which indicates that flying today apparently has not changed much in the last 15 years. In this case, the term vertigo and spatial disorientation are being used synonymously.

While 96% of the population had experienced spatial disorientation in our sample of 2,000 only 37.6% considered it to have been a hazard. To simplify the discussion of the flight conditions associated with spatial disorientation the percentages for occasional and frequent experiences are combined in the last column of Table 2. The most frequent factor noted was poor visibility. 72.5% of the pilots experienced bouts of spatial disorientation under Instrument Flight Rules (IFR) while only 5.4% experienced this condition under Visual Flight Rules (VFR) during the day. Other frequent flight conditions included: flying wing formation-61.1%; banking greater than 20 degrees-52.9%; banking less than 20 degrees-48.3%; climbing-39.1%; straight and level flight-38.3%; airplane in a glide-33.5%; doing a roll-33.5% and lack of sleep-33.5%; reflections from one's windshield-36.9%.

Table 2 shows that every one of the factors listed was associated with the onset of spatial disorientation on more than one occasion and in a number of individuals. These results suggest that many factors must be involved in producing any particular case of disorientation. Another conclusion is that spatial disorientation is a relatively common experience with 96% of all pilots experiencing it at least once in his flying carreer.

With a large number of pilots experiencing the syndrome and 37% feeling that it had endangered their flights on one or more occasions one would expect that spatial disorientation would be a significant factor in aircraft accidents. With this in mind, accident data from the Naval Safety Center for the calendar year 1969 was evaluated for accidents in which disorientation and/or vertigo was listed as a causal or contributing factor.

During 1969 there were 712 accidents (Table 3). Forty-eight (6.75%) of these accidents were coded for vertigo/disorientation as having contributed or caused the accident. Upon analysis of these 48 accidents it was found that only seven (0.98%) had positive evidence that spatial disorientation played a part in causing the accident. Thirteen accidents were presumably erroneously coded as there was no evidence to indicate disorientation/vertigo. In the remaining 28 cases vertigo/disorientation was listed as a possible cause. But, the presented evidence was either not sufficient to validate disorientation or sufficient to exclude it as a cause of the accident. The following extracts from the case histories are classic examples of accidents coded for disorientation/vertigo which are considered to be completely erroneous in that disorientation or vertigo are not even mentioned:

Case 1

While attempting an in-flight refueling, the receiving aircraft was sprayed with fuel which leaked from a faulty drogue. A fire developed and the pilot ejected...

Case 2

While attempting a night landing without runway lights, with a fogged windshield and attempting to avoid an aircraft which had just landed, the pilot allowed the RPM to drop causing a hand landing. The aircraft rolled on its side. .

Case 3

During a spin recovery training flight the student induced a stall spin attitude. After each recovery the aircraft returned to a spin. The instructor took control but was unable to effect a complete recovery. Investigation revealed that failure of the instructor to apply proper spin recovery technique was the cause

of mishap...

Case 4

The Medical Officer's Report indicates most probable cause of the accident was the instructor pilot performing an unauthorized low level maneuver, which investigation revealed he had performed on previous flights with other students...

Case 5

Aircraft was taken by crew chief on unauthorized flight and flown for 45 minutes. The aircraft crashed when he attempted to land...Clinical examination revealed the man was intoxicated and had been drinking heavily for three days prior to the incident.

Case 6

Aircraft experienced a tail rotor malfunction which resulted in a crash landing. On impact the aircraft burst into flames. The crew escaped the burning aircraft...

The following case is a classic example of geographic disorientation which should not be confused with or coded as spatial disorientation.

Case 7

Aircraft was on night cross country. An alternate Air Force Base was selected for landing due to weather at planned landing field. Pilot indicated he had field in sight and disclosed an emergency due to low fuel and requested an arrested landing. The pilot made his approach and landed but he had the wrong field...

Case 8

This case is a good example of pilot disorientation but the disorientation had no relationship to the cause of the accident.

Aircraft experienced compressor stalls and after relight procedure failed, the pilot ejected. He was recovered without injury. The Medical Officer's Report notes the pilot experienced some degree of disorientation prior to ejection while passing through thunderstorms.

Case 9

This case is an example where the cause may have been spatial disorientation but there is not enough evidence presented to conclude that disorientation was, in fact, present and a contributing factor to the accident.

Pilot returning from his first night bombing mission, with very marginal weather apparently became disoriented or distracted and flew the aircraft into the water approximately seven miles from end of runway. The Medical Officer's Report indicates fatigue (induced by stressful flight in marginal weather and self induced diet), plus failure of supervisory personnel to cancel flight for inexperienced pilot, due to weather conditions, contributed to the accident.

Case 10

This case is one of the few examples where there was adequate evidence to classify the accident as to the pilot's disorientation.

While attempting a night Controlled Carrier Approach the pilot experienced vertigo and disorientation. His disorientation and confusion increased with each pass. On the third pass the aircraft struck the ramp...

Of the 48 accidents attributed to disorientation, 47 occurred either at night or under IFR conditions. The one case which occurred during the day was in a plane performing aerial combat maneuvers with another aircraft. All of the seven accidents judged to have been caused by the pilot's disorientation occurred under conditions of reduced visibility.

CONCLUSIONS

In reviewing these accidents and from the results of the 2,300 aviator survey, several conclusions can be drawn.

(1) Spatial disorientation is a common experience, with 96% of all pilots experiencing it at least once.

(2) The highest incidents of disorientation occur either at night or under IFR conditions.

(3) The incident of disorientation occurs just as frequently with straight and level flight as it does with maneuvers.

(4) The next highest incident of disorientation occurs when flying wing formation.

(5) The majority of accidents listing disorientation as a factor either are erroneously coded or the reports fail to provide sufficient evidence to validate a diagnosis of disorientation.

Taking the above conclusions into account it is apparent that in almost all cases where disorientation is present the visual component is the major sensory system affected.

While it has been accepted by many that the vestibular system is the major system involved in producing disorientation in the aviator, with millions of dollars spent on vestibular research, the incidence of disorientation has not been reduced in the past 15 years. It is also evident that the diagnosis of disorientation is misused and applied to many accidents without any real evidence that the pilot was, in fact, disoriented.

From the evidence presented it appears that the primary cause of disorientation is reduced vision and not abnormal stimulation of the vestibular system.

While, at least for calendar year 1969, it does not appear that disorientation is a major cause of accidents, it's high prevalence among aviators and the feeling by a third of these pilots that it has been a hazard to their flying, supports the necessity for a strong research program in spatial disorientation.

It is recommended that a renewed research effort be started to delineate the visual aspects of disorientation and establish methods to offset the reduction of visual stimulation during periods of IFR and night flying.

New efforts should be made to reevaluate the use of the word "disorientation" in determining the cause of aircraft accidents. This effort should include better training of Flight Surgeons in investigating and evaluating accidents. Finally, a better program for training pilots as to the problems of disorientation resulting from reduced visual inputs is needed.

1. Hixson, W., Niven, J., Spezia, E., "Orientation Error Accidents in Regular Army UH-1 Aircraft During Fiscal Year 1967: Relative Incidence and Cost" Army-Navy Joint Report USAARL and NAMRL Report #NAMRL 1108, Aug 1970, p. 2-5.

2. Clark, B. and Graybiel, A. "Vertigo, as a Cause of Pilot Error in Jet Aircraft" Research Report #44 NAVSCHAVMED Dec 1956, p 2.

DISCUSSION

GUEDRY. You have made a critical evaluation of the 48 accidents in which disorientation was coded, but you have not applied the same analytic procedure to the other 650 accidents in which disorientation was not itemized.

FURR. Disorientation was coded if it occurred at any time during the accident, but in 20 cases the disorientation could not be considered as either a primary or contributory cause of the accident. For example the pilot might have reported that he was disorientated following ejection due to a fire caused by spillage of fuel during in-flight refuelling. Disorientation/vertigo was coded because it was mentioned during the accident enquiry, but it was not in any way a cause of the accident. In only 7 out of 48 incidents was there a clear indication, usually given by the aviator, that disorientation was a prime cause. In the 650 accidents in which disorientation was not coded I defer to the Safety Center's analysis.

COLLINS. I believe that I might express one of your conclusions more cautiously in that comparison of your data with those of Clark & Graybiel does not indicate that there has been no change in the amount of disorientation experienced, but only that the percentage of Navy pilots who have experience of disorientation has not changed. It would of course be difficult to determine whether the frequency and intensity of disorientation has remained the same.

With regard to the aetiology of disorientation. it is probably the interaction of visual and vestibular input that is important. For example, a pilot almost always has some visual reference in the form of the instrument panel, if nothing else. But if that visual reference is not fixed relative to the earth, the visual information will be made to agree with vestibular information. Thus, if as a result of aircraft motion a pilot senses by vestibular inputs that he is spiralling down and to the right, his cabin will also appear to spiral down and to the right. The vestibular sensation is thereby visually reinforced. However, if the visual information is about objects fixed relative to the earth, the visual information will predominate.

FURR. In reference to your first comment - Yes, I agree; only the percentage of Naval aviators who experienced (or have experienced) disorientation seems to remain the same. I do not know, and it would be of value to know, if there has been a quantitative change. Our paper gives some qualitative data.

Likewise, I can only agree with your second comment. But, how often have Naval aviators been troubled with the Coriolis effect? Not often, though they know what it is. The point of the paper is that the disorientation incidents we see in naval aviation arise from reduced visual stimulus, not vestibular stimulation as a result of altered g forces, angular accelerations, etc. My point is that we need a better artificial visual stimulus in the cockpit. Research is needed to give sound criteria for the design of cockpit instrumentation so that the pilot's visual environment within the aircraft, is as good as that provided in day VFR flight.

COLLINS. Yet no matter how good a visual display is provided, when the pilot has a powerful vestibular stimulus, the display (say a head-up display) can appear to move in the same manner as the erroneous vestibular sensation and hence reinforces the disorientation. I am not suggesting that the head-up display is not a good idea, but it will not answer all problems of in-flight disorientation.

FURR. Now therein lies the challenge to those who design instrumentation systems for us.

PSYCHOPHYSIOLOGICAL AND ENVIRONMENTAL FACTORS AFFECTING DISORIENTATION IN NAVAL AIRCRAFT ACCIDENTS

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This paper presents those psychophysiological and environmental factors, 12 in number which most affect disorientation related mishaps. These factors are listed in order of number of occurrence and it is indicated that often multiple factors are coded in conjunction with disorientation. Examples of disorientation related mishaps are presented to demonstrate psychophysiological and environmental factor involvement.

In addition, a graph comparing attack and fighter pilot flight exposure to disorientation mishaps is charted to demonstrate the effect of experience upon control of disorientation. The chart indicates that flight experience does play a role in deterring of disorientation mishaps.

Disorientation, a condition experienced by most normal individuals at one time or another, continues to be a degradation to flight performance in naval aviation. Disorientation is noted as a factor in nearly 10% of the Navy's aircraft mishaps. Because it is a common occurrence, almost all naval aviators have experienced it some time during their flight career, with many having repeated exposures. Aviators are ordinarily capable of controlling disorientation and recovering normal flight. There are, however, instances where disorientation progresses to a point at which control is lost. Such was the case of a naval pilot on his first bombing mission who became disoriented in marginal weather and flew the aircraft into the water, approximately seven miles from the end of the runway. Limited experience was listed as a factor. It was, however, not the only one. The Medical Officer's Report of the accident reported fatigue (induced by stress of flight and a self-induced diet) as an additional factor. As this accident aptly illustrates, disorientation episodes are very often accompanied by one or more psychophysiological or environmental factors which weigh heavily on cause or control.

To document those factors which occur most frequently with disorientation and which may have an apparent effect upon it, a two year review of naval aircraft mishaps involving disorientation was undertaken. The period covered Calendar Years 1969 and 1970.

The U. S. Naval Safety Center's Medical Officer's Report, a portion of the complete Aircraft Accident Report codes 116 psychophysiological and environmental factors which affect aircraft mishaps. It is possible, therefore, to report as many as 115 factors in conjunction with or in addition to disorientation. This paper deals with those factors which may have affected either cause or control of a disorientation episode. Of the 115 possible codes 72 were recorded in conjunction with the 102 disorientation cases reported for 1969 and 1970. For the sake of brevity and to provide realistic reporting those factors which had a number of occurrences less than 10 were eliminated. Twelve factors remain which can be considered to have affected disorientation mishaps. They are listed in descending order of numbers of occurrences (Figure 1).

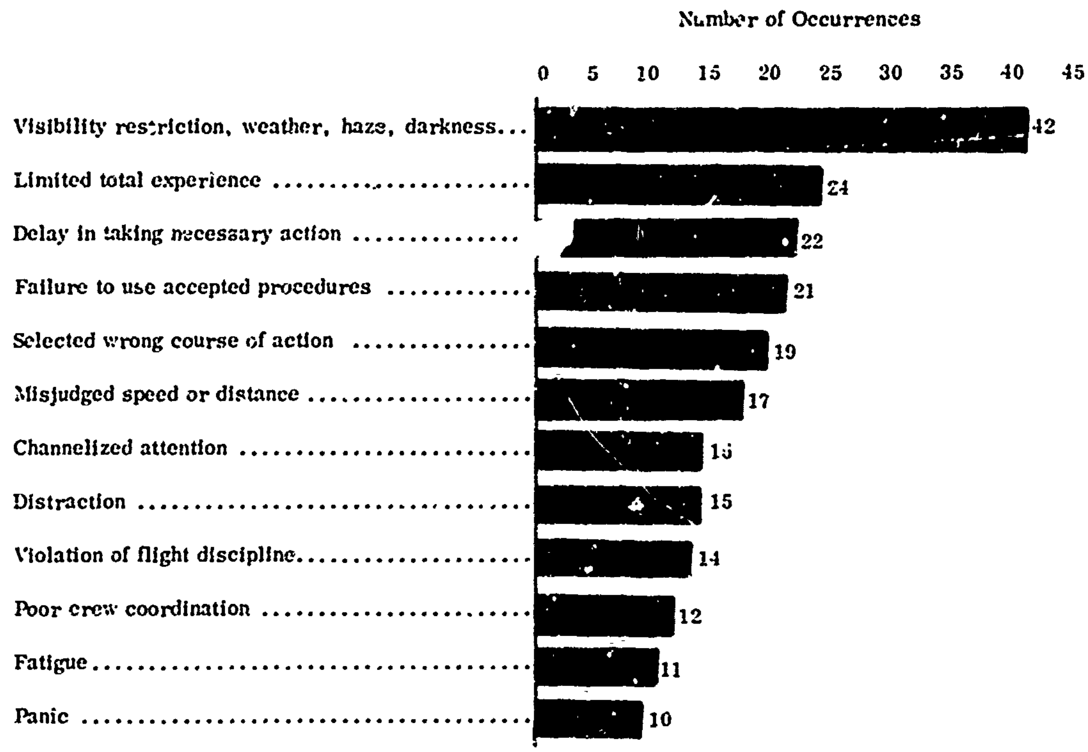

Figure 1

These 12 factors accounted for 53% of the total citations of psychophysiological and environmental factors associated with disorientation. The first, visibility restriction--weather, haze, darkness itself accounted for 10%. Night operations and flights into marginal weather are a continual problem particularly for inexperienced aviators. In one accident, a pilot attempting a night carrier controlled approach became disoriented. His disorientation and confusion increased with each pass until on the third pass the aircraft struck the ramp. In an approach to a landing at night with extremely poor visibility in rain and with a cross-wind, another pilot apparently mistook the white runway edge's stripe for the center line. He touched down slightly to the left of the edge stripe, overran the nearest bunker and continued down the runway. The pilot remained with the aircraft and fortunately received only minor injuries. The Medical Officer's Report indicated that an additional factor once again, fatigue, was also present.

As mentioned previously, it is not uncommon for more than one psychophysiological or environmental factor to be present in an aircraft mishap. In a number of cases an accumulation of factors may collectively bring about a mishap. A training aircraft with an inexperienced instructor and student aboard crashed during a formation training flight. The Medical Officer's Report states that the mishap may have been a result of an inexperienced instructor (factor 1) attempting a low altitude unauthorized maneuver (factor 2). Include disorientation and we have three factors affecting this mishap. This case, of course, is only one of several. In fact, there were very few of the 102 disorientation mishaps in which no additional factor was coded. Only four of the 102 cases or a mere 4% were recorded alone (Figure 2). The remaining 98 cases had as few as one or as many as seven additional factors listed.

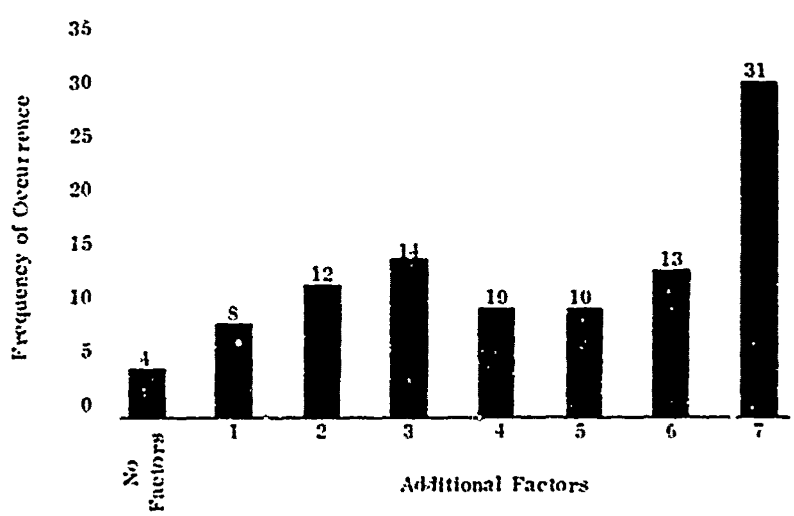

Figure 2

Seven is the maximum number of additional factors which can be computer recorded. In 31 of the 102 disorientation cases, (33%), the maximum of seven additional factors were coded.

An A-4 on a bombing and tactics mission, during a tactics run overshot, performed two acrobat maneuvers and broke off. The aircraft began a gentle roll right while in a nose-up attitude with about 90 degrees angle of bank. The pilot neutralized the controls but the aircraft continued to roll in a stalled condition. When he found the aircraft would not respond to lateral stick movements he checked the turn and bank indicator. Both the needle and ball were pegged to the right. Assuming he was in an inverted spin he applied full left rudder and reduced the power. He noticed no aircraft response and because he was below 10,000 feet he ejected. The pilot apparently lost advantage during a tactics flight and in an attempt to keep the pursuing aircraft in sight became somewhat disoriented, failed to recognize a developing situation and lost control of the aircraft. Seven psychophysiological and environmental factors (Figure 3) were coded in this mishap in addition to disorientation.

<u>A-4 Psychophysiological and Environmental Factors</u>

1. Limited total experience.
2. Failure to use accepted procedures.
3. Channelized attention.
4. Misjudged speed or distance.
5. Selected wrong course of action.
6. Excessive motivation to succeed.
7. Misinterpreted instrument reading.

Figure 3

Note that the first five of the seven additional factors are included among those 12 factors (Figure 1) which were considered to have the majority of effect upon disorientation occurrences.

One final disorientation mishap is discussed because it involved a naval flight surgeon/aviator in control of a jet aircraft. He was attempting a night ground control approach with weather 200 feet and one mile visibility, which was below standard minimums. The pilot was high on the glide slope and was given a wave off. The aircraft continued down the runway with gear and flaps down before attempting to turn. Approximately 40 seconds later the aircraft impacted the ground, with no attempted ejection. It is suspected that disorientation may have occurred when the pilot returned to instruments after attempting a VFR fix. The pilot was also limited in actual night instrument time. Again, there are seven psychophysiological and environmental factors (Figure 4) in addition to disorientation.

<u>Flight Surgeon/Aviator- Psychophysiological and Environmental Factors</u>

1. Failure to use accepted procedures.
2. Visibility restriction - weather, haze, darkness.
3. Poor crew coordination.
4. Disorientation.
5. Violation of flight discipline.
6. Faulty preparation of personal equipment.
7. Inadequate weather analysis.

Figure 4

And, here again, five of the seven additional factors recorded were among those which ranked highest as factors affecting disorientation. These cases illustrate that disorientation is seldom the result of a single factor, but rather occurs from the interaction of multiple factors operating together. One of the most important of these factors is the experience of the pilot. It is fairly well accepted that the more flight experience a pilot logs, and the more training he receives, the greater his chances of overcoming disorientation.

In order to document the theory that the chronological experience is an asset to deterring or controlling disorientation, the distribution of years of experience of fighter and attack pilots involved in disorientation mishaps was compared to the population exposure distribution for this group. Details of the exposure curve are given in an earlier Safety Center report.

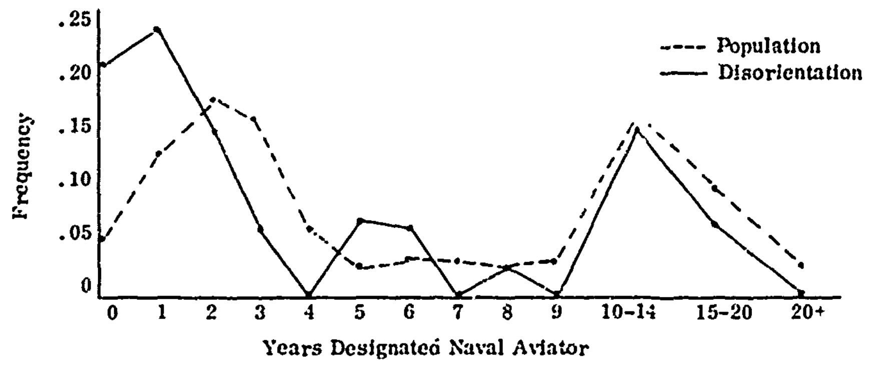

Figure 5

The broken line represents population exposure for attack and fighter pilots as a function of the number of years as designated naval aviators (DNA's), while the solid line indicates the distribution of disorientation mishaps for the fighter/attack group. The attack and fighter pilots were chosen for charting because of the larger numbers of disorientation episodes occurring within that community. The authors believe this to be the first attempt within the U. S. Navy to examine the effect of flight experience on disorientation occurrences with flight exposure controlled. The comparison indicates a high potential risk for disorientation mishaps within the first two years of designation with a decline as experience increases up to the fourth year. After the seventh year of designation the curves appear to stabilize, and additional experience produces no further reduction. Within limits, the greater the number of years of flight experience the pilot has, the lower his chances of a disorientation mishap. Experience does play a role in control of disorientation.

In summary it appears that the 12 factors discussed are most significant in affecting disorientation occurrences and their outcomes. One of these factors, experience, was shown to be of great importance in deterring disorientation with the first two years of flying much more hazardous than the later years. It is a most complex problem and in order to solve it we must attempt to eliminate or reduce the impact of the factors which are critical in the genesis of disorientation episodes and the control of these episodes once they occur. Such improvement will come only from responsible flight scheduling which considers environmental and psychophysiological exposure as well as training and flight crew experience.

REFERENCES

1. Earl H. Ninow, Norman E. Lane and Gerald T. Eccles, Pilot Experience and Pilot Caused Carrier Landing Accidents, Naval Safety Center.
2. Medical Officer's Report, Naval Safety Center, 1969-1970.

DISCUSSION

O'CONNOR. I would like to point out the similarity between your last figure (Fig. 5) and the incidence of psychiatric illness in aircrew. There is a high incidence in the first few years with a second peak in later life perhaps due to the effects of many hours flying and the stresses of life. Do you think this similarity is significant and if you do, what is the reason for it?

NINOW. I agree. The second peak would appear to represent aviators of an age and experience in whom the 'fear of flying' syndrome is most frequently seen, probably due to increased family responsibilities as well as the protracted demands of the military career.

DISORIENTING EFFECTS OF AIRCRAFT CATAPULT LAUNCHINGS

by

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SUMMARY

The Naval Air Development Center Human Centrifuge Facility was used to simulate the acceleration profiles encountered in aircraft catapult launchings. Twelve subjects attempted to keep a continuously moving target at subjective eye level before, during, and after exposure to simulated catapult launch accelerations. Our results demonstrated that subjective eye level was changed by exposure to the accelerative forces. The change in subjective eye level persisted, in some cases, for as long as three minutes after the simulated launch sequence was completed. The results are discussed in terms of the effects of rotated acceleration vectors on human spatial orientation, and the data are related to certain types of aircraft losses that have been reported following catapult launchings at night.

INTRODUCTION

When an aircraft is launched from the deck of a carrier, the pilot is exposed to a sudden and dramatic change in the accelerative forces acting on his body. He is pushed sharply back into his seat as the aircraft hurtles forward, accelerating rapidly to attain adequate airspeed. Although the acceleration is of but brief duration, lasting for only two to four seconds, it is of sufficient intensity that the pilot may be disoriented during its application and for some time thereafter.

The G_x (chest-to-spine) acceleration experienced by the pilot is vectored with gravity, and the combined gravitational-inertial acceleration vector is increased in length and rotated as the catapult forces are applied. At the end of the catapult stroke, the accelerative forces are removed, and the vector resumes its natural G_z (head-to-foot) orientation. Thus, the combined gravitational-inertial acceleration vector changes rapidly both in length and direction. For an acceleration of 4.0 G_x, the resultant vector is rotated approximately 76° and increased in length by more than 4.12 times.

The illusions and perceptual-motor effects that accompany changed acceleration vectors have been described in the literature by several investigators (1-6), and certain of the mechanisms that underlie them have been well documented (7, 8). Further, the probable significance of the illusions in so-called "dark night takeoff accidents" has been elucidated in detail (9).

For the most part, however, experimental research has been concerned with the effects of small amplitude and long duration, rather than large amplitude and transient, accelerations. Because quantitative information concerning the effects of suddenly applied, short duration, accelerative forces on illusions of spatial orientation is extremely limited, the current experiment was undertaken.

METHOD

Subjects

Twelve volunteer male subjects served in this experiment. Of the twelve men, six were U.S. Navy pilots who had experienced aircraft catapult launchings in the preceeding six months period, and six were enlisted men without catapult experience. The subjects ranged in age from 21 to 39 years, with a mean of 34 years; they ranged in height from 165 to 191 centireters, with a mean of 179 centimeters; they varied in weight from 62 to 97 kilograms, with a mean weight of 79 kilograms.

The subjects underwent a thorough medical examination before they were selected for the experiment; all were judged to be in excellent physical health and to be free of any visual, motor, or vestibular abnormalities.

Apparatus

The data to be reported here were all collected at the Naval Air Development Center Human Centrifuge Facility. A detailed description of the facility may be found elsewhere (10, 11). The normal orientation of the subject in the gondola of the centrifuge was modified in this study so that the pitch gimbal was used as a yaw gimbal. By controlling the yaw angle, the tangential (G_T) and radial (G_R) accelerative forces were vectored to provide a linear acceleration in the G_x, or chest-to-spine direction.

Figure 1 illustrates the manner in which the centrifuge was used to simulate the accelerative forces encountered in aircraft catapult launchings.

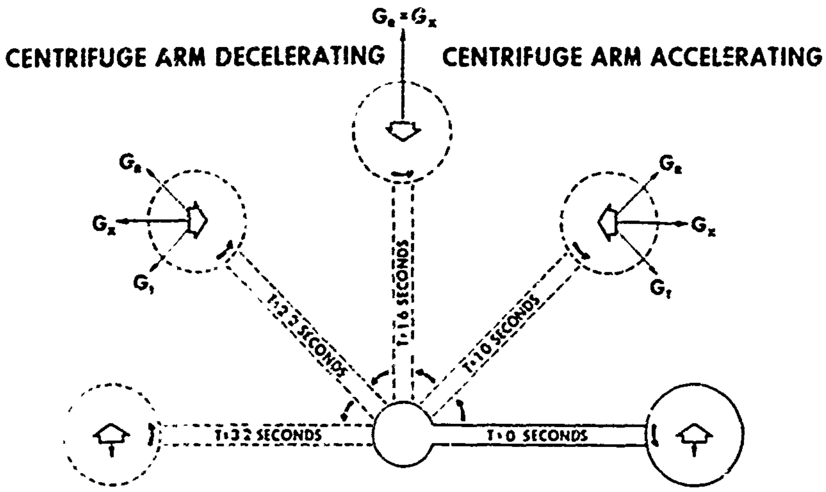

Figure 1 - Schematic representation of a catapult simulation on the human centrifuge.

The subject is seated facing the direction of the open arrows. At T = 0 seconds, the centrifuge arm begins to turn, leading to a rapid onset of tangential acceleration (G_T). As the velocity of the centrifuge arm increases, radial accelerations (G_R) are generated. The subject is rotated counterclockwise by the yaw gimbal so that the chest-to-spine (G_X) accelerative forces always lie along the resolution of G_T and G_R. At T = 1.6 seconds, G_T approaches zero, and G_X is identified by G_R. At T = 3.2 seconds, the centrifuge arm comes to rest. The subject is now facing in the same direction as he was at the beginning of the simulation, having been rotated through approximately 180° by the centrifuge arm, and 180° by the yaw gimbal.

In a typical catapult launch, the pilot is exposed to an impulse acceleration of 2 to 4 seconds that peaks at 3 to 5 G_X. The centrifuge simulation approximates these values very closely, and Figure 2 presents a simulataneous comparison of the centrifuge simulation with an actual catapult launch acceleration profile.

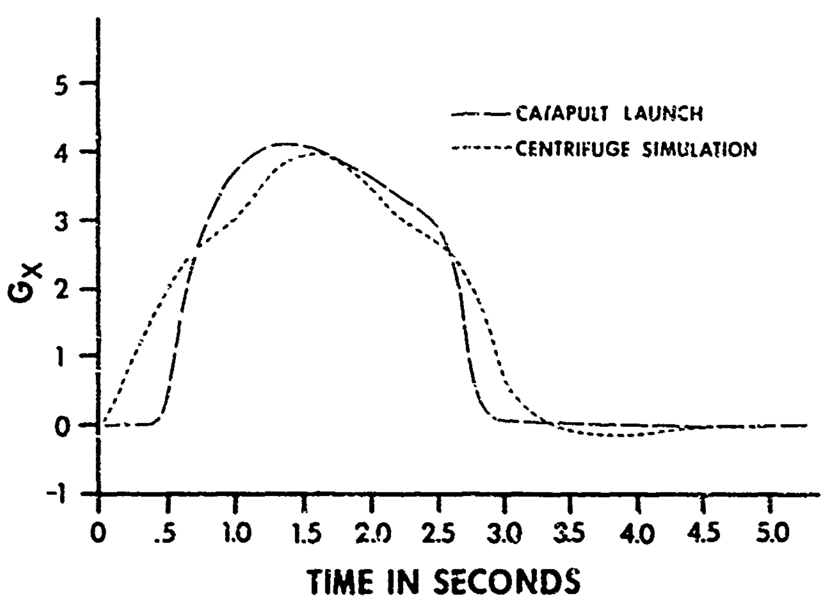

Figure 2 - Comparison of the G_X accelerations recorded in catapult launch and centrifuge simulation.

The apparatus used to present the test stimulus and to measure changes in its apparent elevation is illustrated in Figure 3.

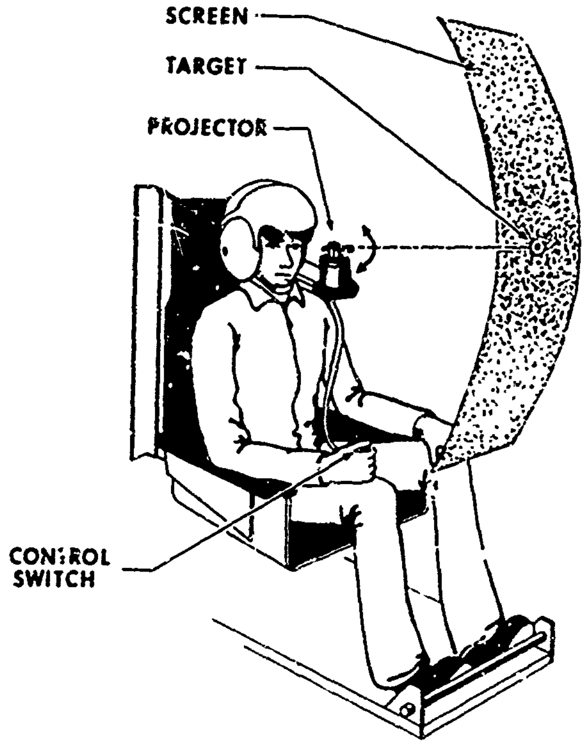

Figure 3 - Apparatus used to measure changes in apparent target elevation

The apparatus consisted of a servo-driven image projector and a white s at a radius of about 92 centimeters. The projector cast a 25-millimeter outer diameter anu (target) on the screen at a distance of approximately 92 centimeters from the subject's e, only the target was visible in the otherwise totally darkened gondola.

At the beginning of each data collection session, the position of the subject's seat was adjusted so that his eyes were in line with the axis of the projector. After this adjustment was completed, the subject sat in the darkened gondola for about 2 to 5 minutes while calibrations were performed on the apparatus.

Following the calibration period, the experimenter activated the servo motor and image projector. The servo motor continuously drove the target either up or down at a rate of 5 degrees per second. The subject, who was provided with a control switch that reversed the direction in which the target moved, continuously bracketed the position that he considered to be at his eye level.

All twelve subjects underwent four sessions in which data were collected. The sessions lasted for five minutes each, and exactly 120 seconds into the session, the subject was exposed to the simulated catapult launch accelerations depicted in Figure 2. In order to assure that the subjects were not unduly startled or surprised by the rapid acceleration, a five-second count-down to the catapult simulation was begun exactly 115 seconds into each session.

Data were collected continuously throughout each session, and the output of the servo follower was monitored on strip chart and magnetic tape recorders. The output signal, which was analyzed on line with the aid of an EAI analog computer (Model 231-R), was averaged over each ten-second period of the session. The mean of each ten-second average was then computed across all four sessions for each subject. The first ten of these ten-second means was averaged to provide a baseline for each subject, and all data were then evaluated as deviations from this mean baseline value.

RESULTS

Mean measures of the subjects' performance in setting the target to apparent eye level are presented in Figure 4. The data are plotted to show the magnitude of the illusion in degrees as a function of time into the experiment. Positive illusion values indicate that an immobile target would appear to be elevated, and negative values indicate that an immobile target would appear to be depressed. Since the subject continuously adjusted the position of the target to keep it at apparent eye level, positive values were obtained when the target was lowered below the subject's baseline, and negative values were obtained when the target was raised above the baseline.

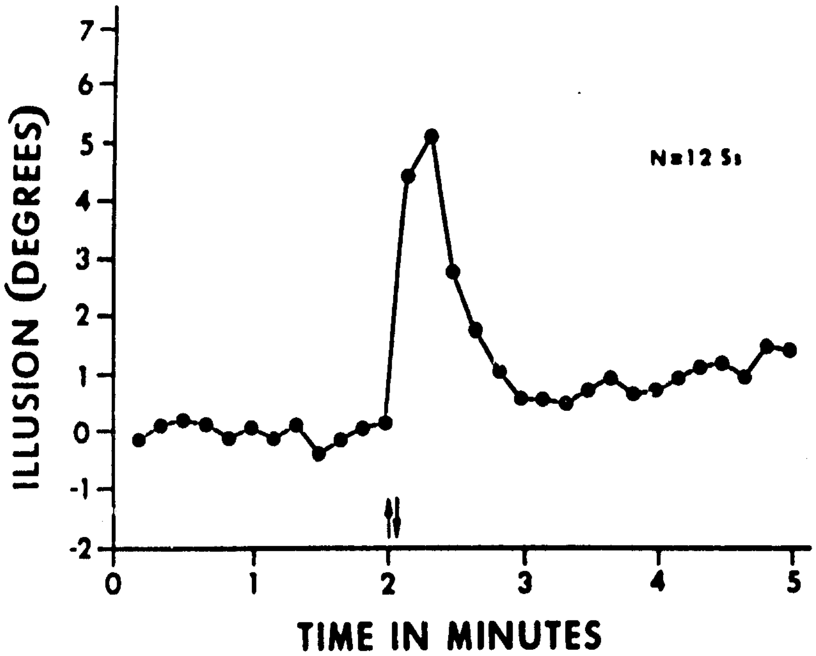

Figure 4 - Illusions of apparent target elevation due to simulated catapult launches.

Initially, the subjects performed quite well, and there was very little variation in the settings of the target to apparent eye level. The simulated catapult launch (shown by the up and down arrows on the abscissa) led to a dramatic change in settings to apparent eye level. The illusion appeared within the first few seconds following onset of the catapult simulation, and it persisted for some time thereafter.

For purposes of statistical analysis, the data from each session were sampled in three 30-second segments: the initial 30 seconds, the 30-second period immediately following the catapult simulation, and the final 30 seconds. The magnitude of the illusion was examined as a function of the previous experience of the subjects (pilots vs. naive), and the particular data segment sampled. Previous experience with catapult launches was not found to be statistically significant ($F<1.00$), nor was its interaction with the data segment sampled ($F<1.00$). The data segment sampled, however, was highly significant ($F = 8.40$; d.f. = 2/102; $p<0.001$).

Eleven of the twelve subjects tested demonstrated illusions during the 30-second period immediately following the catapult simulation. The range of illusions obtained from individual subjects across each 30-second data segment were: -1.83° to +2.28° for the initial 30 seconds; -1.14° to +10.78° for the 30-second segment immediately following the catapult simulation; and -3.30° to +5.23° for the final 30 seconds.

The results indicate, quite unambiguously, that transient G_x accelerations lead to illusory changes in apparent eye level that can persist long after the G_x accelerations are terminated.

DISCUSSION

The illusions demonstrated in this experiment may very well have great functional significance under conditions in which the pilot does not properly monitor his flight instruments. Consider a pilot who has just completed a night catapult launch from the deck of a carrier. In the absence of external visual cues, the pilot normally is unable to differentiate the catapult launch forces into their inertial and gravitational components. Thus, the pilot may experience an illusory pitch-up attitude. Even if his aircraft were in straight and level flight, his entire array of cockpit instruments would appear to rise before him. In fact, the aircraft would probably be climbing in a nose-up attitude, and the illusion would be compounded with this, making the pilot believe that his angle of attack was excessive. The natural "correction" would be to ease forward on the stick, reducing the "excessive" angle of attack. At this point, the aircraft could be placed in a dive, but the pilot would still perceive himself to be climbing.

Further complications would occur upon flap retraction. The resulting downward pitch and subsequent increase in airspeed could lead to effects similar to those brought about by the catapult launch accelerations. These effects probably could combine with the catapult launch effects, and result in still greater illusions. The momentary distraction from flight instruments due to flap retraction, coupled with increased illusions could make the situation still more hazardous. The results could be disastrous.

A promising line of research, with a goal towards eliminating these dangerous illusions was recently suggested by Cramer and Wolfe (12). They argue that ". . . the magnitude of the resultant vector. . .depends upon conditions of acceleration. It should be possible to learn to make psychophysiologic determinations of the length of this vector and to use this in conjunction with prior information on the length or direction of the gravity vector in achieving appropriate pitch control under a number of conditions. . ."

Whether or not a training program could eliminate hazards due to illusions of pitch under transient high-amplitude accelerations as well as under long term low-amplitude accelerations is a matter for emperical investigation. At present, however, it seems clear that there is no adequate substitute for careful, conscientious, and accurate monitoring of flight instruments.

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DISCUSSION

WOLBARSHT. What was the scatter of the subjective estimates of target light position, and could any of the differences you found be attributed to the experience of the subjects?

COHEN. The scatter was large; unfortunately I do not have the data with me so I cannot give precise values. In the experiment we used both naive subjects and experienced pilots; the data points from the two graphs overlapped, so we cannot say experience has a significant effect on the illusory perception.

BENSON. The simulation was not identical to the 'real life' situation in that, in the centrifuge, the subject was exposed to an angular movement in yaw of 180°. Do you think that this motion influenced the perception of target light position?

COHEN. Probably not. Although the simulation did not identically reproduce the real life situation, and although the subjects were rotated by 180° about the Z-axis, there is no a priori reason that I know of why this should significantly influence their perception of the target's elevation. Also, when asked about the sensations of the catapult simulation, none of the subjects reported that they even felt the rotation about their yaw (Z) axis.

BENSON. I think it is most gratifying to see experimental evidence which accounts for an illusory perception of pitch attitude after a brief exposure to a Gx acceleration, as the illusory perception associated with longitudinal accelerations (eg on overshoot) has not been explained adequately in the past on the basis of the 'oculogravic illusion'. What do you think is the reason for the long persistence of the illusion after the relatively short duration acceleration employed in your experiments?

COHEN. I don't really know, but transient overloading of a sensory system often leads to effects that have slow decay rates. Intense auditory, visual, or tactile stimulation can often result in positive after-sensations long after the stimulation itself has been removed. With semi-circular canal stimulation, long term after effects have been well documented. With the otoliths, though, the picture is not so clear-cut. I think that, rather than the length of stimulus application, the rise time and peak intensity are the more important in determining the persistence of the illusions. But I just don't have the data to determine the specific basis for the persistence, except to say that it probably is at least partially vestibular in origin.

BENSON. In addition to the illusion in pitch attitude which you have demonstrated, in actual flight correction for the illusory pitch attitude produces a curved flight path and an additional change in the direction and magnitude of the acceleration vector, which may further accentuate the illusion.

COHEN. Yes, I quite agree.

GUEDRY. I also found your paper most interesting. Is it possible to produce a real change in pitch, involving angular acceleration about the Y-axis, during or just after Gx acceleration? I ask this because there are changes in pitch involving angular accelerations during catapult launches, which act in the same direction as the rotation of the resultant linear acceleration vector.

COHEN. Your point is well taken. The extra upward rotation about the y-axis at the end of the catapult stroke could contribute still further to the illusion. Also, under those conditions. there would be no question about semi-circular canal stimulation. Unfortunately, we are not able to provide the extra upward pitch on our centrifuge because our normal pitch gimbal is used to yaw the subject during the acceleration. However, with some modifications, it may be possible to include the upward pitch, as you suggest. It certainly is worth considering.

DOBIE. I have a small observation concerning the oculo-gyral illusion (OGI) and flying experience. In studies carried out on RAF aircrew, no relationship could be shown between the cupuiogram characteristics of some 600 subjects and their flying experience - from 'naïve' to current aerobatic pilots - when the OGI end point was used in sensation cupulometry.

COHEN. Your comment is very interesting. At the physiological level, there is probably no difference between the responses of experienced and naïve subjects. Also, from my data, the illusions do not differ significantly with the subjects' previous flight experience. Without specific training to discriminate between Gx accelerations and changes in pitch attitude, the value of experience will probably show up only in actual flight performance. The illusion is most likely to be as strong in experienced pilots as in naïve subjects, but the experienced pilots generally attend to, and believe in, their instruments. As long as the instruments are correct, and as long as the pilots respond as their instruments indicate, everything will be OK. It is when the pilot gives in to his illusory sensations, and disregards his instruments that he gets into trouble.

COLLINS. Your findings of 'long-term' effects of vestibular stimulation is of particular interest to which I might add a supportive, if non-quantitative, observation. In many CAMI demonstrations of Coriolis effects, in which the subject on the turntable was enclosed by an illuminated cabin, a given head movement might give a sensation of 'climb' and the cabin would appear to tilt upward.

After several seconds, the cabin would (visually) appear to reach an almost 'straight-and-level' attitude, though some subjects would report a slight but persistent 'nose-up' attitude for a minute or more. Since these were only demonstrations, we went ahead with another head movement, so we have no quantitative data regarding the persistence of the effect. However, it does support your results regarding long-term effects of relatively 'impulsive' vestibular stimulation. These phenomenon also appear to be associated with a visual environment that is not fixed relative to the earth.

COHEN. Thank you for your observations. I think that a good deal of research needs to be done on the illusions brought about by 'impulsive' vestibular stimulation. Also, the persistence of these illusions after the stimulus is terminated merits further study.

EFFECTS OF ACOUSTIC STIMULI ON THE VESTIBULAR SYSTEM

by

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SUMMARY

Several investigators have suggested that high intensity noise stimulates the vestibular system, since numerous subjective reports of disorientation, nausea, and giddiness have been reported. In the present study, nystagmography, vertical perception, and a rail test of human equilibrium were used to measure the response of human subjects to acoustic stimulation. No nystagmus was obtained and the perceptions of the vertical task yielded no consistent effects, however, the rail task was quite sensitive to acoustic stimulation. Decrements on the task of 20% to 35% were obtained in high intensity noise of 140 dB even when subjects wore ear protectors. In other experiments, levels as low as 100 dB were found to produce an adverse effect on the task. The results are discussed as a possible effect of the action of high intensity noise on the vestibular system.

INTRODUCTION

Ades (1) reviewed a number of studies concerning man's ability to maintain his orientation during exposure to high intensity acoustical energy. Many instances of equilibratory and postural disturbances were cited such as vertigo, nausea, nystagmus, visual field shifting, feeling of forced movement, and staggering and falling. An asymmetrical noise condition, where there were unequal stimulus intensities at the two ears, produced the most disturbing effects. Ades further emphasized that future studies should concentrate more on broadband noise environments that simulate the spectra of jet engines, since this is the practical operational problem. In the review a number of conclusions were drawn: "The first sensory system after the auditory to be assaulted by intense noise is the vestibular.-- In the frequency range 300 - 3000 cps, thresholds for vestibular stimulation were approximately 135 - 150 dB for the unprotected ear. The most sensitive range was 1000 to 1500 cycles." These levels seem very high, and the person exposed to such intense levels for other than a short period of time is in serious danger of suffering permanent threshold shifts in hearing. There is the possibility that vestibular effects have been demonstrated at much lower levels than those cited above. For example, in a study by von Bekesy, head deviations, of the order of a millimeter, were obtained in response to noise levels as low as 100 dB. Further, von Bekesy found that vertigo was produced in his subjects by a two minute exposure to a tone of 100 Hz at 120 dB pulsed three times a second. Ades accepts the validity of these findings, however, he points out: "Our own endpoints are relatively crude, but our threshold values are probably closer to the sound levels at which acoustic stimulation of the vestibular apparatus may become practically significant." Of course, practical significance is difficult to define, and depends mainly on the task a man is required to perform, not only during exposure to the noise but for an undetermined amount of time after the exposure. Further, even though a result may not be of immediate practical importance, it may have considerable theoretical significance if it gives some understanding of the manner in which acoustical energy stimulates the vestibular system.

Dickson and Chadwick (2) have pointed out that it is difficult to determine if the vestibular system is being stimulated from subjective comments. They conducted interviews with individuals working in the vicinity of operating jet engines to obtain their subjective experiences when standing in certain critical noise locations. They found that "descriptions varied and were vague," but were best described by "one of the engineers who said he experienced a momentary sensation of imbalance accompanied by a lack of power to think." Most studies up to the present time have used subjective measures with a very small sample of experimental subjects. It seems particularly important to use objective measures in future studies since a considerable decrement might occur in the ability of an individual to maintain his balance and orientation before he becomes consciously aware of dizziness, nausea, incoordination, etc. Particularly valuable would be a measure of nystagmus which would give a direct indication of the involvement of the vestibular system. The major obstacle to this approach, when subjects with normal hearing are used, is the elicitation of nystagmus at noise levels that do not produce a hazard to the hearing of the subjects. Ades et al (3) avoided this problem by using deaf subjects, and presented acoustic stimuli up to 170 dB. The difficulty with deaf subjects, of course, is that they may differ considerably from normals in their vestibular sensitivity, since damage to the auditory system almost invariably affects the vestibular system. However, the authors (3) report that of the six subjects in their study, two showed normal nystagmus to caloric stimulation, and "The other four showed varying degrees of retention short of complete. All of these subjects also reacted as normals with respect to the oculogyral and oculogravic illusion--" For the two normal subjects, they found nystagmus thresholds of 120 dB - 135 dB in the 250 Hz to 600 Hz frequency range and thresholds approximately 20 dB higher in the 1000 Hz to 2000 Hz range. Nystagmus was also elicited by a band of jet engine noise at a threshold level of approximately 135 dB. Subjective reports of dizziness in the study were not consistent, possibly due to a communication problem, and dizziness was not reported at all frequencies where nystagmus was obtained. The results are puzzling, sometimes dizziness was reported before nystagmus and sometimes not at all. Ades and coworkers were aware that the thresholds for nystagmus elicitation in deaf individuals might be atypical and they recommend that studies with normal subjects be conducted.

The present paper summarizes a large number of studies conducted at the Aerospace Medical Research Laboratory. Several of these have been presented at scientific meetings or have been released as AMRL

Technical Reports, and for these experiments detailed descriptions of experimental and statistical procedures will not be given here.

NYSTAGMUS AND SUBJECTIVE JUDGEMENT EXPERIMENTS

An attempt was made to duplicate the findings of Ades et al (3), using four laboratory workers who volunteered to participate in the experiment. A pure tone of 590 Hz at 135 dB with a 5 second exposure period was presented to the subjects. This frequency seemed to be the most sensitive one for subjects in Ades' study. A broadband jet engine type of noise of 140 dB (upper curve in Figure 1) was also presented. Only a five second exposure was presented to each ear of a subject in a 24 hour period. Electronystagmography was used to record both horizontal and vertical eyemovements. All subjects were tested in total darkness and instructed to keep their eyes open. Darkness was used to eliminate visual fixation that might obscure the nystagmus response. No nystagmus was produced by the pure tone or the broadband noise stimulus. The noise was reported as subjectively unpleasant and highly arousing, however, there were no indications of vertigo or dizziness. After this experiment was completed, one of the subjects was exposed to 590 Hz at 135 dB for a ten second duration with the tone pulsed three times a second. A vigorous defensive eyeblink reflex in time with the stimulus was obtained but no nystagmus or vertigo. Our results, indeed, suggest that the vestibular system of normal hearing subjects responds differently to acoustic stimulation than does the vestibular system of deaf subjects. However, the elicitations of nystagmus may be related to the duration of exposure. Although Ades also used a 5 second exposure duration he made repeated exposures in his attempts to find thresholds, that is, he proceeded in progressive steps by gradually increasing the noise intensity with a 5 second exposure period used at each intensity.

The stimulus for our next investigation was a 120 dB, 100 Hz tone, pulsed three times a second for a duration of two minutes. This is the condition which was reported to produce dizziness and nausea in von Bekesy's subjects (1). The four subjects used in the previous experiment and 15 volunteer male college students served as subjects. No nystagmus was obtained and no symptoms of vertigo or nausea. At this point, five college students with a history of motion sickness were compared with a group of five students who had never been motion sickness. Again the results were negative; no nystagmus and no subjective reports indicating vestibular stimulation. Next, we tested two laboratory workers, both in their late thirties, who were susceptible to motion sickness to the point that they were sometimes troubled by car sickness. Still there was no evidence of vestibular response. Finally, negative results were obtained with the four laboratory personnel, used previously, but this time a 1000 Hz tone was used instead of the 100 Hz tone, (von Bekesy (4), reports small reflexive head movements were obtained at 1000 Hz). Thus our attempts to obtain nystagmus and subjective vestibular symptomotology by exposing subjects to intense acoustic stimulation have proven unsuccessful.

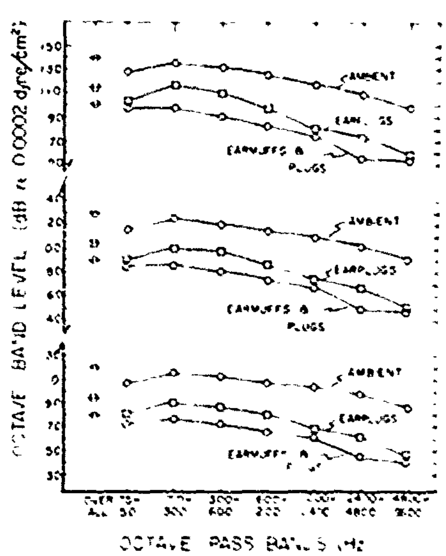

Figure 1. Ambient wideband noise spectra and calculated noise levels in ear canal after reduction of noise by ear protection.

EXPERIMENTS USING THE RAIL TASK

At this point in our investigations we decided to use a rail balancing task developed by Graybiel and Fregley (5) for measuring human equilibrium. These investigators have presented some evidence that this battery shows sensitivity to variables that are primarily vestibular in nature. They have shown that individuals with little or no vestibular sensitivity performed on the rails at a level comparable with the lowest 3% of the labyrinthine normal population. Rail performance of labyrinthine defectives was unaffected by the consumption of alcohol while that of normal subjects was adversely affected. They have also related performance on the task to canal sickness susceptibility, to threshold caloric response, and to response to severe sea conditions. The rail task consists of 6 rails, 8 feet in length, on which the subject is asked to perform three tasks. Rails were 2.75, 2.25, 1.75, 1.25, .75, and .5 inches wide before being covered with a 1/16 inch fiberglas material to prevent breaking and splitting of the rail edges. The three tasks consisted of (a) standing in a heel-to-toe manner on each of the six rails with eyes open, (b) standing with eyes closed, and (c) walking heel-to-toe-to-heel on each of the six rails. In our research, we have presented only part of the original task and made slight changes in the procedure. In early experiments (6) we found parts of the rail task to be insensitive to the effects of noise and for some parts of the task to always yield perfect scores. Most subjects performed perfectly on the three larger rails when standing with eyes open or when walking. Conversely, the two smallest rails were quite difficult for most subjects, for both rail walking and standing with eyes closed. Parts of a task too difficult or too easy for most subjects usually produces a measure that is relatively insensitive to experimental variables. For our version, we have dropped the rail walking part of the task because of suspected unreliability, and measured standing eyes open and eyes closed performance on only two rails. On two rails, 2 1/4 in. wide and 1 3/4 in. wide, the subjects were required to stand with their eyes closed, and on the other two rails, 1 1/4 in. wide and 3/4 in. wide, the subjects stood with their eyes open. The score for both measures was the time, to the nearest second, from when the subject assumed the correct position on the rail until he violated his position (lifted a foot) or fell off the rail. The maximum score for each trial was 60 seconds. If the subject was still balanced on the rail at the end of this time, the trial was discontinued. Subjects in most of our experiments were given five trials on each rail. The maximum score for each measure was 600 seconds, that is, five trials x two rails x the maximum possible score per trial of 60 seconds.

Five different groups of subjects were tested in a study on the effects of broadband, high intensity noise on human equilibrium (7). Subjects were all tested in the same type of counterbalanced design and four different ambient noise conditions were presented to each group: control (70 dB), 120 dB, 130 dB, and 140 dB (re. 0.0002 dyne/cm^2). The first group of subjects tested wore earmuffs and earplugs; the second group wore earplugs, and the third group wore earplugs with one earmuff covering the right ear to produce an asymmetrical exposure (see Figure 1). Only one experimental condition was presented to each subject in a 24 hour period.

Analysis of variance revealed no significant effects for the eyes closed portion of the rail task. This is surprising, since with vision excluded the vestibular system should play a larger role in maintaining equilibrium. The means for the 140 dB noise condition were smaller than the means for the control condition in every case, but because of the large variability of the scores no significant effects were obtained. By using more subjects or by increasing the number of trials a more clearcut reaction to noise should be obtained. The eyes open measure was quite sensitive to the effects of noise. A significant effect for noise intensity was obtained in the analysis of variance for four of the five groups in the present experiment. The extent of the differences seems to support previous observations that asymmetrical noise has a more detrimental effect on human equilibrium than symmetrical noise. At the lower intensity levels (120 dB and 130 dB), there was a small improvement in performance over the control for the symmetrical noise exposures and a significant decrement in performance for the asymmetrical exposure. At 140 dB decrements were obtained with all three groups, and as expected, the results showed more decrement for group 2 (earplugs) than for group 1 (earplugs and muffs), and more decrement for group 3 (earplugs & 1 muff) than group 2. In two additional groups, tested on the rail task immediately after termination of the noise, detrimental effects were obtained only for an asymmetrical exposure group and not for a symmetrical exposure group. These data are plotted in terms of percent change from the control in Figures 2 and 3.

In the experiment just described (7) large decrements were obtained in the length of time subjects could remain balanced on the rails in the high noise exposure of 140 dB regardless of the type of ear protection given the subjects. Ambient noise at this intensity stimulates the receptors of the skin, muscles, joints and perhaps the vestibular as well as the auditory system. Therefore, the decrements in equilibrium could have resulted from auditory stimulation, from extra-auditory stimulation, or from both in combination. In order to evaluate these effects separately, an attempt was made to reproduce the levels and spectra of the noise in the ear canals that occurred during whole body exposure (8). Specifically, we attempted to simulate through earphones the levels and spectra that occurred in the subjects' ear canals during 140 dB ambient stimulation when they were wearing both earplugs and earmuffs (overall level of 100 dB), earplugs alone (overall level of 115 dB), and earplugs with one earmuff covering the right ear (overall level of 100 dB to the right ear and 115 dB to the left ear). This was not a straightforward procedure since the levels and spectra in the ear canals in the previous studies were not physically measured. Instead, the values were calculated by subtracting from the ambient noise levels the attenuation values of the ear protectors worn. Therefore, the actual noise in the ear canals was only approximated. Further, there was undoubtedly some conduction of the acoustic energy to the inner ear by tissue and bone. No attempt was made to add a bone conduction component to the simulation.

Sixteen subjects were tested in a counterbalanced design with each subject receiving all four conditions of control (approximately 60 dB), symmetrical (100 dB in both ears), symmetrical (115 dB in both ears), and asymmetrical (115 dB in the left ear and 100 dB in the right ear). Only the standing eyes open part of the rail task was presented to the subjects, and the mean trial performance for conditions was as follows: control - 32.83 sec, symmetrical (100 dB) - 29.55 sec, symmetrical (115 dB) - 28.92 sec, and asymmetrical - 30.07 sec. An analysis of variance conducted on the data revealed a significant effect for noise conditions ($p < .05$). The means for the three noise conditions did not differ significantly, however, all differed significantly from the control condition. The decrements in performance, expressed as percent change from the control are plotted in Figure 2 along with the changes obtained in the previous experiment.

Subjects performed better in the control condition in the present experiment (see Table 2) than they did in the previous experiment. This difference could have been due either to the difference in the ability of the respective groups or due to differences in experimental design. Nevertheless, the comparisons made in terms of the percentage change from the control seem valid. Noise effects on the eyes open part of the rail task were much less with only ear stimulation than with ambient noise. If acoustic energy in the ear canal was the determining factor for producing degradation of performance, the results should have been approximately the same. The two symmetrical exposures in the prior investigation produced approximately twice as much decrement as the symmetrical exposures in the present experiment, and for the asymmetrical exposures four times as much decrement was obtained. Therefore, there was a failure to replicate the asymmetrical - symmetrical effect of the prior investigation as well as the absolute size of the performance decrement. These results suggest that extra-auditory stimulation is not a simple additive factor to the level of noise in the ear canal in producing performance decrements, otherwise decrements with ear canal stimulation alone should have been reduced proportionally for asymmetrical and symmetrical exposures. The conclusion seems justified that combined auditory, extra-auditory stimulation produces greater detrimental effects on human equilibrium than auditory stimulation alone.

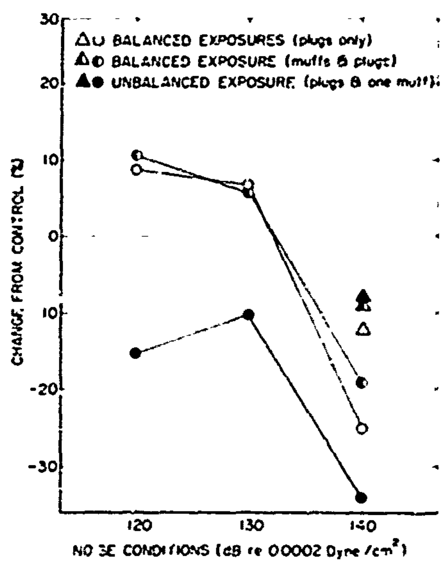

Figure 2. Percent change from control group means for the three groups with differing ear protection, and the means for the group presented comparable intensity levels through earphones.

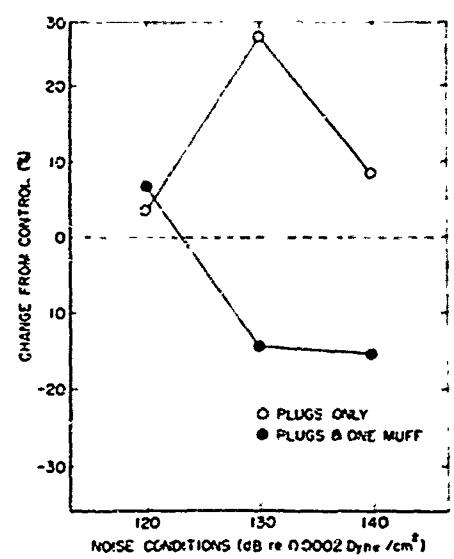

Figure 3. Percent change from control group means for means obtained at each noise level for eyes open measure for the groups tested immediately after exposure to the noise.

A demonstration that the rail task is maximally sensitive to 590 Hz would seem to be evidence that the task is reflecting the direct effect of acoustic stimulation on the vestibular system. Such results would be in agreement with the study of Ades et al (3) where 590 Hz produced nystagmus in deaf subjects at a lower sound pressure level than the other frequencies used in the study. However, the vestibular system of deaf individuals may be maximally sensitive to different frequencies than the vestibular system of subjects with normal hearing. In fact in an early study (9), normal hearing subjects were used in an attempt to determine the threshold of vestibular stimulation at several pure tone frequencies. Subjects showed the lowest thresholds at 1000 to 1500 Hz when a slight shift in the visual field was used as a measure of vestibular stimulation. However, both of these studies were exploratory in nature and, even for the small number of subjects used, the responses were not consistent across subjects. Therefore, these results can only be considered as suggestive. Nevertheless, if the rail test does reflect the effects of vestibular stimulation then perhaps some evidence can be obtained to indicate differential frequency sensitivity. To investigate this possibility, both standing eyes open and standing eyes closed performance on the rails were measured in normal hearing subjects during exposure to pure tone acoustic stimulation (10). Subjects were tested during exposure to test frequencies of 100, 260, 590, 1500, and 2500 Hz, and a control condition. One group of 24 subjects (male college students) were presented the test stimuli at intensity levels of 95 dB in the left ear and 75 dB in the right ear (asymmetrical exposure). The other group of 24 subjects were presented the tones at a level of 95 dB in both ears (symmetrical exposure). The subjects came to the laboratory on seven different occasions, the first time was a practice period, and the last six times to perform the rail task while exposed to each of the stimulus frequency conditions used in the

experiment. Each subject experienced all conditions according to a counterbalanced experimental design. Separate analyses of variance were performed on the eyes open and eyes closed scores on the rail task for both groups. Again, as found in previous experiments, the eyes closed measured showed no statistically significant sensitivity to the acoustic stimulation either for symmetrical or asymmetrical exposure. Similarly, no significant effects were obtained in the analyses of variance for the eyes open measure. However, the effect for frequency of stimulation approached significance ($p < .10$) at the 5% level of confidence for the asymmetrical exposure group. Although the value obtained did not reach a customary level of statistical acceptability, it was decided to test differences between frequencies of pure tone stimulation because the greatest decrement occurred at the expected frequency of 1500 Hz (see Table 1). The effects of different frequencies of pure tone stimulation were analyzed by use of a Sign Test (11). For asymmetrical exposure, a significant decrement at 1500 Hz was obtained relative to the control group ($p < .01$), and 1500 Hz also differed significantly from 100 and 590 Hz ($p < .05$). There was no significant difference between the results obtained at 1500 Hz and the results obtained at 260 and 2500 Hz. The difference, however, was in the expected direction with $p < .10$ and $p < .20$ obtained, respectively. It will be recognized that significant differences between these means does not correspond to the size of the difference, that is, there was a larger difference between the means at 1500 Hz and the mean at 260 Hz than between 1500 Hz and 100 Hz, however, in the former case the difference was not significant while in the latter the difference was significant. The Sign Test is a measure of the consistency of the difference; it takes into account only the direction of the difference and not the size of the difference. The results seem to support the hypothesis that the eyes open part of the rail task is sensitive to stimulus frequencies found in the von Gierke et al (9) study to produce the most direct effects on the vestibular system. This result occurred within the frequency range (1000 to 1500 Hz) where individuals perceived a slight shift in the visual field at the lowest intensity level. However, these results should be viewed with caution since there was a relatively large number of subjects tested in the experiment and still only a borderline significance was obtained.

TABLE 1

MEANS FOR STANDING EYES OPEN MEASURE

Broadband Noise (N = 52)	Control	120	130	140
Earplugs & Muffs	26.46	29.62	20.20	21.61
Earplugs	24.01	26.54	25.86	18.42
Earplugs & 1 Muff	25.41	21.74	23.21	17.04
Aftereffects				
Earplugs	16.80	17.68	21.56	18.42
Earplugs & 1 Muff	19.36	20.86	16.90	16.75

Auditory Along Study (N = 16)	Control	Plugs & Muffs	Plugs	Plugs & 1 Muff
	32.83	29.65	28.92	30.07

Pure Tone Study (N = 48)	Control	100	260	590	1500	2500
Asymmetrical	24.46	23.60	24.91	24.27	21.53	23.88
Symmetrical	23.35	23.62	23.50	21.96	24.46	24.60

PERCEPTION OF THE VERTICAL EXPERIMENTS

One hypothesis to explain the decrements we have obtained on the rails is that the noise effects the subject's perception of the vertical and makes it more difficult for them to maintain their equilibrium. This hypothesis seemed promising since reports of shifts in observers' visual fields during presentation of extremely intense noise imply an effect on the perception of the vertical (9). Also, Dickson and Chadwick (2) suggest that high intensity jet noise may have its effects on the linear motion receptors because of their failure to observe nystagmus in subjects exposed to high intensity jet noise.

In our research on the perception of the vertical, a total of 75 male college students were used as subjects in five separate experiments. The same pure tones and broadband noise as previously used with the rail task were presented. There were four days of testing in all experiments, except for the pure tone study conducted at 105 dB. On the first day the subjects were given preliminary training, and subsequently, they came to the laboratory for three more days of testing. During the last three days, they were given a symmetrical exposure (equal intensity of acoustic stimulation in each ear), an asymmetrical left exposure (greater acoustic stimulation in left ear), and asymmetrical right exposure (greater intensity in right ear). Both order of presentation of pure tone frequency or noise intensity, and symmetrical-asymmetrical conditions were counterbalanced across subjects. On the preliminary training day subjects were given 60 practice trials on the perception of the vertical task. On the three test days a control condition of six

trials was presented before each noise intensity condition or each pure tone frequency, and one block of six trials was presented during each acoustic exposure. During the broadband noise experiment, ignoring counterbalancing, a subject received control - control, control - 120 dB, control - 130 dB, and control - 140 dB. During pure tone exposure, the subject received control - control, control - 100 Hz, control - 260 Hz, control - 590 Hz, control - 1500 Hz, and control - 2500 Hz. In the broadband noise experiment the subjects wore: earplugs (115 dB in each ear at ambient level of 140 dB) for the symmetrical exposure; earplugs with one muff covering the left ear (100 dB in left ear and 115 dB in right ear at ambient level of 140 dB) for the asymmetrical right exposure, and earplugs and one muff covering the right ear for the asymmetrical left exposure. The pure tone stimuli were presented through headphones with the tone directed either to both ears or the left or right ear depending on condition. Four experiments were conducted with the pure tones, a 95 dB level was presented in the first two experiments with the only difference between experiments being the manner of presentation of the perception of the vertical task. In the next experiment 100 dB was used, and finally in the last experiment 105 dB was used. In the latter experiment only one day of testing was conducted and only one condition was given. The subjects were tested in the asymmetrical left condition at frequencies of 260 Hz, 1500 Hz, and the control (see Table 2).

In these experiments subjects were required to adjust a line until it appeared to be vertical. In two experiments (95 dB pure tone and the broadband noise experiment), the line consisted of an aluminum rod which was 1/2 in. in diameter and 3 feet long, and painted with phosphorescent paint. The rod was mounted on a circular piece of plywood, 4 feet in diameter, painted flat black. The only source of illumination in the experimental room (a reverberation chamber for broadband noise exposure) was a "black light" which was located approximately four feet from and directed to shine on the aluminum bar. The reflector of the black light was covered with black construction paper, and the light shone through a 1/2 in. x 1 in. aperture cut in the paper. The subject sat in a straight back chair at a distance of twelve feet from the apparatus, and the rod was presented with the center at approximately the eye level of the subject. The vertical perception task was changed for the remaining experiments and a vertical line was presented inside an 18 in. x 18 in. x 36 in. box painted a flat black. The experiments using this apparatus are indicated in Table 2 by "Box". The vertical line inside the box was 16 in. long and consisted of a hollow tube 5/32 in. in diameter. The tube was filled with phosphorescent material and the same black light, as used in the previous experiments, was directed on it. The box was placed on a wooden platform, and the subject (S) sat on an adjustable stool. An adjustable bite bar mounted directly inside the box opening was used to control for possible differences in head position. Regardless of which task was used for the perception of the vertical, the same procedure was used. The rod was displayed by the experimenter (E) either 30 degrees clockwise or 30 degrees counterclockwise. Once the rod was displaced by E, he then signaled the S to make his judgement. The subject made his setting by pressing a toggle switch which via an electric motor moved the rod at a constant speed, with the direction of press of the toggle switch determining the direction of movement of the bar. Subjects were allowed to retrace until satisfied with their setting. Once the subject completed his setting he pressed a button, located on a small box with the toggle switch, which activated a light at E's station, and E made the reading, displaced the bar, signaled the subject, and the cycle began over again. With the exception of the preliminary training period in which the subject received 60 trials, testing was conducted in six trial intervals with the bar displaced an equal number of times in the counterclockwise and clockwise directions. The score used in the subsequent statistical analysis for each subject was the algebraic difference between the mean of the six setting for the control and the mean of the six settings during acoustic stimulation. Deviations from the vertical were measured in degrees with those displacements to the subjects' right (clockwise) given a positive value, and those to the subjects' left (counterclockwise) given a negative value. Recording accuracy was within 1/4°.

Analyses of variance were performed on all the data obtained in the experiments on the perception of the vertical. The only significant effect obtained was for the asymmetrical right condition using discrete frequencies at 95 dB with the large perception of the vertical task. The effect was obtained for frequency of stimulation. The noise exposure at 260 Hz was significantly different (based on difference scores) from control, 100 Hz, 1500 Hz, and 2500 Hz. The mean difference scores between 260 Hz and 590 Hz did not differ significantly. In Table 2, it can be seen that the differences were due largely to differences in the prestimulus control periods rather than due to differing settings in the noise. Therefore, it seems quite unlikely that this is a genuine finding and that there is actually a differential effect on the perception of the vertical due to frequency of acoustical stimulation. The fact that none of the other analyses of variance yielded a significant effect for acoustical conditions argues against any interpretation of acoustical stimulation having an effect on the perception of the vertical.

In all studies using pure tone stimulation there was a constant error in the alignment of the bar to the vertical. Subjects tended to displace the rod to the counterclockwise side of the vertical. There are a number of possible explanations for this, the most likely seems to be that the right hand was used for all subjects in setting the bar to the vertical. Nevertheless, the error was quite small under all conditions, and the scores easily fall into the range of error reported by previous investigators (12). There was also a constant error for the broadband noise experiment but in the opposite direction to that obtained for pure tone exposure. Again, as was the case for pure tone exposure, the reason for this error is not obvious. When the same testing apparatus was used with the 95 dB pure tone group the constant error was in the opposite direction. The fact that these experiments were conducted in different rooms may account for the difference in the direction of constant error. The broadband noise group, who had the constant clockwise error, was tested in a reverberation chamber. This chamber contained three large acoustic horns which could be seen faintly in the subject's left field of vision. Therefore, previous literature on the perception of the vertical task (for a review see Howard and Templeton, 1966) would suggest that the asymmetry of the chamber or the knowledge the subjects had of the location of the sound source may have produced the constant error. Nevertheless, the perception of the vertical task used in the present experiment did not show any consistent sensitivity to noise which was of primary interest.

TABLE 2

MEAN ALGEBRAIC ERROR IN DEGREES FOR PERCEPTION OF VERTICAL EXPERIMENTS

	Control	100	260	590	1500	2500
95 dB - Exp. (N = 18)						
Symmetrical						
control	-.35	-.25	-.11	-.17	-.05	0
noise	-.17	-.08	-.07	-.30	-.07	+.06
difference	+.18	+.17	+.04	-.13	-.02	+.06
Asymmetrical Right						
control	-.47	-.54	-.79	-.67	-.43	-.13
noise	-.58	-.59	-.39	-.58	-.49	-.45
difference	-.11	-.05	+.40	+.09	-.06	-.32
Asymmetrical Left						
control	-.32	-.29	-.36	-.25	-.18	-.24
noise	-.27	-.26	-.36	-.22	-.15	-.21
difference	+.05	+.03	0	+.03	+.03	+.03
95 dB - Box (N = 18)						
Symmetrical						
control	-.36	-.38	-.17	-.44	-.48	-.45
noise	-.22	-.28	-.54	-.53	-.53	-.72
difference	+.14	+.10	-.37	-.09	-.05	-.27
Asymmetrical Right						
control	-.33	-.38	-.53	-.55	-.41	-.58
noise	-.23	-.38	-.50	-.67	-.77	-.72
difference	+.10	0	+.03	-.12	-.36	-.14
Asymmetrical Left						
control	-.31	-.52	-.53	-.38	-.53	-.48
noise	-.34	-.40	-.78	-.54	-.52	-.61
difference	-.03	+.12	-.25	-.16	+.01	-.13
100 dB - Box (N = 18)						
Symmetrical						
control	-.28	-.27	-.34	-.37	-.16	-.38
noise	-.33	-.12	-.18	-.15	-.30	-.47
difference	-.05	+.15	+.16	+.22	-.14	-.09
Asymmetrical Right						
control	-.38	-.20	-.35	-.36	-.35	-.42
noise	-.37	-.42	-.59	-.53	-.35	-.50
difference	+.01	-.22	-.24	-.17	0	-.08
Asymmetrical Left						
control	-.33	-.38	-.12	-.08	-.33	-.20
noise	-.42	-.31	-.10	0	-.20	-.23
difference	-.09	+.07	+.02	+.08	+.13	-.03
105 dB - Box (N = 9)						
Asymmetrical Left						
control	-.24		-.65		-.60	
noise	-.53		-.74		-.73	
difference	-.29		-.09		-.13	

(Continued)

TABLE 2 (Continued)

Broadband Noise (N = 12)

	Control	120	130	140
Symmetrical				
control	+1.01	+1.32	+1.44	+1.04
noise	+1.14	+1.40	+1.08	+ .77
difference	+ .13	+ .08	- .36	- .27
Asymmetrical Right				
control	+1.10	+1.10	+1.20	+ .74
noise	+1.11	+ .82	+ .79	+ .59
difference	+ .01	- .28	- .41	- .15
Asymmetrical Left				
control	+ .58	+ .92	+ .81	+ .72
noise	+ .74	+ .58	+ .56	+ .36
difference	+ .16	- .44	- .25	- .36

DISCUSSION

The direct effect of intense sound on the vestibular system as indexed by nystagmus or subjective report has not been confirmed in our experiments. However, there seems little doubt that under some circumstances noise does affect the vestibular system. There have been too many subjective reports in the operational situation of dizziness, blurred vision, and vertigo to doubt that such effects do occur. Possibly, the greater complexity of the operational environment accounts for the difference. It is particularly true that the auditory exposure for our subjects and for individuals working around operating jet engines is greatly different. In many operational situations, a few steps in any direction or even changes in the position of the head relative to the noise source may make a considerable difference in the noise intensity and asymmetry of exposure that the man experiences. Also, working in close proximity to operating jet engines is a hazardous task in itself. There is the constant pressure of getting the aircraft back into commission quickly, while avoiding ingestion by intakes, and being burnt by contact with hot parts of the engine. Davis (13) states: "In the military situation the very loud noise, which not only stimulates the ear very powerfully but also calls other sensory organs such as touch into action, certainly adds to the total stress of what is already a difficult and perhaps dangerous overall situation. This is something that must be heard and felt to be appreciated." And indeed, even in the laboratory, at levels of 140 dB and higher, it must be experienced to know what it is like.

Some of our subjects have reported a few of the symptoms that have been observed in the operational situation, such as excessive fatigue after noise exposure, reduction of tactual sensitivity, and heat about the earplugs. However, the most common subjective report was one of extreme arousal or alertness. Possibly this intense arousal partly masks sensations arising from the sense organs. In a study on tactual sensitivity in noise, subjects, wearing earplugs, were tested in the same ambient levels of noise used previously with the rail task. We were not able to demonstrate a difference between performance on the task, identifying sheets of sandpaper of different degrees of coarseness, in control and noise periods. Unfortunately, for our results, as well as for two of our subjects, we neglected to control for the degree of pressure exerted on the sandpaper. These two subjects, of the 8 tested, exerted such intense pressure during exposure to the 140 dB noise that they scraped the skin off the tips of their fingers. Neither subject noticed that this was happening at the time. One subject noticed that his finger tips were bleeding after the noise was turned off and his session was terminated for the day. The other individual did not notice it until he was driving back to his residence, some 10 to 15 minutes after termination of the noise. Both subjects left traces of blood on the sheets of sandpaper. This result is similar to numerous anecdotal reports of the blunting of pain during conditions of extreme excitability, as well as agreeing with results on audioanalgesia.

An alternate possibility is that high intensity noise may affect the vestibular system and produce nystagmus only when the system has been somehow biased so that it exhibits increased sensitivity. For example, a predisposition to respond may come about through the use of drugs, exposure to carbon monoxide, ingestion of alcohol (14), or when a bias has developed such that a subject exhibits directional preponderance (DP) in his nystagmus. Some interesting relationships between hearing and DP of nystagmus have recently been reported. Bruner and Norris (15) have correlated hearing threshold asymmetry, and DP of caloric nystagmus. They state: "The greater the threshold difference between ears, the greater the DP, with the DP biased toward the worse hearing ear. The correlation was most prominent at 8000 Hz where the Pearson r was .30 (N = 49). This lateralization of hearing and preponderance became apparent only when a difference of about 5 dB or more existed between the thresholds of the two ears, and since many of the pilots did not exhibit interaural differences of this magnitude, the correlation coefficients are smaller then if bilaterally hearing subjects had been excluded." It would have been interesting if we had used subjects with pronounced asymmetries of thresholds in our experiments on exposure to high intensity sound. However, we carefully controlled for this variable, individuals with a threshold of hearing difference between the right and left ears of greater than 5 dB were not used as subjects in the experiments. Such experiments are planned for the future as well as studies incorporating other predispositional factors.

A second important question concerns why we obtained results on the rail task at levels much lower than those that produced no subjective vestibular effects or nystagmus. There are several reasons to expect decrements in equilibrium in noise intensity fields of 140 dB even when ear protection is worn. In the intense broadband noise exposure that we used there is no doubt that other sensory receptors are affected besides the vestibular, if indeed, the vestibular receptors are affected at all. In fact, there is the possibility that the results we obtained at the 140 dB level were due mainly to stimulation of the receptors of the joints. Howard and Templeton (12) contend that, although vestibular stimulation can greatly affect postural steadiness, the basic physiological mechanism of static upright posture is proprioceptive control from the hip joint and spine. A related finding is reported by Fredrickson & Schwarz (16). These authors, in a study of single units in the vestibular nucleus of cats, found that: "Ninety-nine percent of the units responded to vestibular stimulation and 80 percent to joint movement. There were no responses to muscle pressure, or to optic or acoustic stimuli." They point out further that: "Position information from the joints and vestibular labyrinth appear to ascent together in the central nervous system. We have found that the primary cortical vestibular receiving area in the Rhesus corresponds to that portion of the somatosensory cortex where Mountcastle noted such prominent joint input." It is a long conceptual jump from human performance on the rail task to the electrophysiological and anatomical characteristics of the joint and vestibular receptors in cats and monkeys. Nevertheless, the receptors of the joints and labyrinth may be more intimately related than previously thought, and can serve as one factor in explaining how noise (vibration?) adversely affects equilibrium. In agreement with this, one of the earliest studies (17) conducted on the effects of highly intense sound (jet engine noise and pure tones from 130 to 157 dB), the authors do not mention any effects on the vestibular system. They do mention, along with other symptoms, the vibration of various parts of the body. They state: "Another phenomenon of interest is the subjective sensation of vibration. At frequencies from about 1500 cps down to 700 cps there is a sensation of marked vibration of the cranial bones. At certain frequencies in this range the sensation of vibration is so strong from the lower jaw that one reflexly grits his teeth in an effort to stop the vibration." They also mention that weakness in the knees was noticed while standing close to operating jet engines. They state: "This sensation is not accompanied by faintness or vertigo and is probably not the result of a true muscular weakness. It would appear to result from an effect on the proprioceptive reflex mechanism since with conscious effort one can maintain the normal erect position usually maintained by reflex mechanisms."

Of course, one must still explain why decrements were obtained on the rail task at lower levels of stimulation where there was little or no stimulation of the joints (the noise was presented through earphones). At these lower levels, as well as the higher levels of course, it is possible that the vestibular system is being stimulated but not indicating the fact in the consciousness of the subjects or manifested by nystagmus. There may be a rather wide intensity range to which the vestibular system responds before there are any subjective or nystagmic indications of vestibular stimulation. Consider the possibility that acoustical stimulation, except at very high levels, just causes a diffuse reaction of the vestibular system and does not yield a sensation of turning or one of directionality; the same type of response that occurs to weak motion stimuli. (This, of course, would explain our failure to find a clearcut effect on the perception of the vertical task.) For example, Jongkees (18) in discussing his extensive experimentation on the oscillating parallel swing states: "--the first thing you feel is a certain rhythm, but you do not know what it is, whether it is a displacement or a rotation." Perhaps the same thing is true for the acoustic stimuli we have used in our experiments. The effect is difficult to describe by the subjects because of the oscillatory nature of the stimulus and of course, the rate of this oscillation is out of the frequency range normal for vestibular sensitivity. In an unpublished study we have applied negative pressure in the earcanal of 10 subjects and have been unable to demonstrate a clearcut effect on equilibrium. The failure to demonstrate an effect was due in large part to two subjects who adopted an unusual posture on the rail. They tilted their head approximately 30 degrees toward the side of stimulation and surprisingly, they performed about as well on the rail task with their head tilted as they did in the control condition. It seems quite unlikely that such results would have been obtained with a low frequency oscillating pressure.

Regardless of the hypothesis that is adopted about the particular sensory system most affected by high intensity noise, the results of the present study are important from both an applied and methodological point of view. Important from an applied point of view, since noise levels have been found to adversely affect human equilibrium at levels considerably below those that would be expected to damage hearing. And important from a methodological point of view, because a measure, eyes open measure on the rails, has been obtained which shows considerable sensitivity to noise. This is an important accomplishment, since it now allows us to explore the parameters of the noise stimulus to determine their relative effectiveness in producing decrements in equilibrium. The relative effects of different noise spectra, different frequencies, different lengths of exposure, and intermittent exposures can be explored.

Future studies should be extended to other types of acoustic stimuli than those used in the present study. In particular, the effects of static pressure, and ultra-low frequency sound should be examined. Parker et al (19, 20) have examined both types of stimuli using guinea pigs. They presented stimuli in the frequency range of 0.1 to 10 Hz, as well as static pressure and observed the eye movement response of guinea pigs. They found that with the acoustic stimuli: "--approximately 2.0 - 2.5 in. Hg produced a movement analogous to that seen in normal counterrolling, and is some cases, nystagmus." And "--With static pressures of 1.5 - 2.0 in. Hg, nystagmus was generally elicited following the counterrolling--." Control studies using deaf guinea pigs and those with sectioned 8th nerves leave little doubt that the responses are of a vestibular nature. In interpreting these results with potential application to human subjects, these authors state: "--disturbances of orientation and equilibrium would be expected following rapid pressure changes if the pressure equalization in the middle ear were retarded. This situation would occur if a Eustachian tube were blocked.--" Mohr et al (2) have studied effects of low frequency acoustic stimuli on human subjects for the purpose of determining tolerance limits. From their experiments, they conclude: "The presently available data support the conclusions that noise-experienced human subjects, wearing ear protectors, can safely tolerate broad band and discrete frequency noise in the 1 - 100 cps range for short durations at sound pressure levels as high as 1[illegible]0 dB. At least for the frequency range above 40 cps, however, such exposures are undoubtedly approaching the limiting range of subjective voluntary tolerance and of reliable performance." The period of testing in this experiment was usually only from .25 to two minutes at these levels. In reviewing this investigation, Burns (22) states: "The results provide the necessary information for proper judgements of the effects of such sound to be made. Thus the great merit of this

investigation is the ability it confers to separate real and potential dangerous effects from the vague suppositions and sinister implications which sometimes appear in non-specialist accounts." There is certainly an element of truth in this statement, however, it goes too far. Just because people are willing to tolerate such high level of noise for a couple of minutes, with no apparent damage does not mean that there is no longer any need to be concerned with such levels of noise in terms of performance and physiological changes.

Our studies certainly do not indicate that men cannot work in such high intensity noise since most seem to be fairly efficient. The fact of the matter is that we have only scratched the surface, we do not know what importance if any that our studies have. One study (23), conducted at the same intensities used in the rail study, showed that a discrimination task, combining short term memory and visual discrimination, as well as a hand-tool dexterity test were adversely affected. On the discrimination tasks the subjects made more errors than they did in the quiet, and on the hand-tool dexterity task the subjects took 10 to 15% longer to complete the task than during the control condition. Also, the exposure to the noise was only 10 to 15 minutes, and of course, this does not tell us anything about situations where men go in and out of such noise several (or many) times in one day or are exposed for longer periods of time. In fact the conclusions of the exploratory studies contained in the Benox Report (1, 9) conducted many years ago would apply to the results we have obtained with the discrimination task and the hand-tool dexterity task. The authors of the report conclude: "(a) There was a tendency toward increased time necessary to accomplish a relatively complex psychomotor task. (b) Subjects more frequently forgot or neglected to follow instructions. And (c) There was an urge to work hurriedly and get out of the noise situation." Up to this point in time, we are not able to say very much about the effects of extremely intense noise beyond what was said a number of years ago by the authors of the Benox Report. And over the years the urgency has somewhat gone out of the problem because of a tendency of men in such noise levels to both wear ear protection and to wear more adequate ear protection. However, there is the necessity of taking a more analytical look at the effects of such noise as well as looking at higher levels. The very intense noise characteristic of many military situations has been studied but little. Although there is much literature on the effects of lower levels of noise (up to 115 dB), there is little on the highly intense noise and it is particularly important that the latter be studied more intensively because we are only partly studying the same stimulus that is discussed in the literature on the effects of noise on man.

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DISCUSSION

PERDRIEL. I think that we should not be surprised to note an influence of noise on vestibular function as this falls in the category of sensory interactions. Noise of the level of 110dB indeed causes a decrease in visual performance with the same characteristics as that which was described. Concerning this interaction between noise and vision, it is believed that its effect is situated at the thalamic level. Can one formulate the same explanation for the effect of noise on vestibular function?

HARRIS. In our studies with the high intensity broadband noise many sensory systems are stimulated through the action of airborne vibrations. Therefore, sensory interaction undoubtedly occurred. However, since we were able to produce an even larger decrement with a 1,000 Hz intermittent tone, presented asymmetrically through earphones, I am inclined to think that the vestibular receptors were directly stimulated.

COHEN. May it not be possible, as a control for auditory muscular reflexes, to use subjects with auditory damage but with their vestibular systems intact?

HARRIS. Yes, if one could find such subjects. Most individuals with auditory damage have damage to their vestibular systems as well.

MALCOLM. Is there any possibility that the effects you see are due to reflex response of skeletal muscles to the very high sound levels you use?

HARRIS. Yes, there can be no question about this. There may be reflexes produced both by action of the noise on the auditory system and by a direct action on the skin, muscles and joints.

ALCOHOL INDUCED POSTROTATORY FIXATIONAL NYSTAGMUS, A TRAINING FILM ON A SIMPLE METHOD OF DETECTING SLIGHT ALCOHOLIC INTOXICATIONS IN PILOTS.

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Summary:

This film shows the practical procedure and its nystagmographical correlates. With this test, the flight surgeon has at his disposal a reliable and simple method to detect and thus eliminate from flying pilots in an acute state of alcohol intoxication or with a marked hangover from the night before.

In normal and healthy subjects, postrotatory nystagmus is suppressed by ocular fixation. This is due to the inhibitory effects of a central regulatory system located in the Formatio reticularis. An even slight alcohol intoxication decreases these inhibitory functions, and the subject is not able to suppress postrotatory nystagmus, which then is clearly visible to the examiner. This fact has first been described by MANZ in 1939. On this basis TASCHEN then developed a simple test to detect alcohol intoxications especially for the use in forensic medicine:

While standing, the subject is turned round his vertical axis 5 times within 10 seconds with his eyes open in a room with normal illumination. Then he is stopped abruptly and has to fixate the examiner's finger held 25 cm away from his eyes. A marked nystagmus of more than 4-5 seconds duration indicates an alcohol intoxication with blood alcohol concentrations of 0,5 - 0,8 ‰.

ELBEL, HEIFER and PIOCH then investigated the significance of this test on a large sample of 2800 alcohol intoxicated persons. Fig. 1 shows the increase of mean durations of postrotatory fixational nystagmus in relation to blood alcohol concentrations.

Nystagmographic control tests in the resorption phase (Fig. 2) revealed, that the differentiation between worst results in non-intoxicated and most favorable results in intoxicated subjects begins at 0,3 ‰. Above 0,5 ‰ every postrotatory alcohol nystagmus is clearly distinguishable from every ENG tracing of normal subjects. After a mean blood alcohol concentration of 1,16 ‰ and 2-3 hours after the end of the alcohol ingestion the tests were still positive in the elimination phase with concentrations of 0,7 - 0,9 ‰

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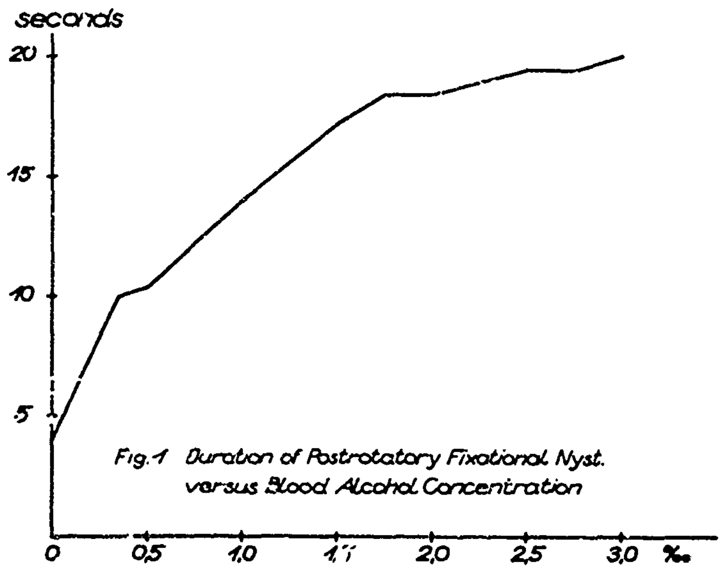

Fig. 1 Duration of Postrotatory Fixational Nyst. versus Blood Alcohol Concentration

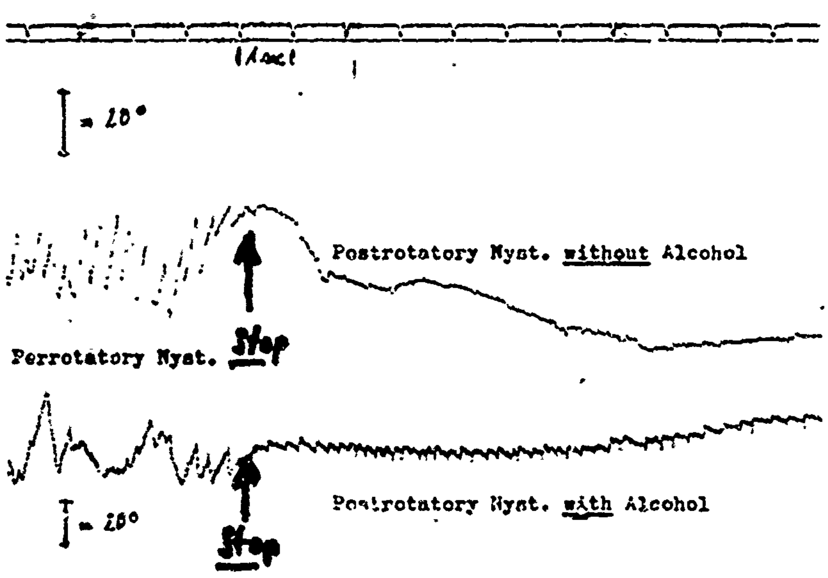

Fig. 2

DISCUSSION

LANSBERG. Just a suggestion: could not the sensitivity of the test be improved by using 10 rotations in 20 seconds instead of 5 rotations in 10 seconds? This would give the cupula time to return to its zero position and respond to the full 180% sec stopping impulse.

FRÖHLICH. This is undoubtedly true, but this test has not been developed for use by ENT specialists. I will make this suggestion to Dr Heifer at the University of Bonn, who has made the most extensive study on this problem.

WOLBARSHT. Isn't the state of light (or dark) adaptation important in determining the amplitude of EOG. Subjects could falsely diminish EOG by controlling his state of adaptation.

FRÖHLICH. This test is only performed in a normally lighted room and the test person is always in a state of adaptation to the ambient illumination. Furthermore, in a clinical setting the nystagmus response is assessed visually and not by electro-oculographic techniques.

BLOOM. Have you used your technique to detect other drug abuse items such as marijuana, heroin, tranquilizers or anti-histamines?

FRÖHLICH. No, we have used this technique only to evaluate the effects of Caffeine or Pervitin on alcohol intoxicated persons. These two drugs did not improve postrotatory fixation; postrotatory nystagmus was not decreased.

ANGIBOUST. During experimental alteration of the state of wakefulness, obtained either by pharmacological agents or simply by sleep deprivation, one observes an important degradation in the form of saccadic eye movements. When the subject was asked to fixate alternatively, and at his own rhythm on two points with an angular separation of 70°, initially, the single saccadic eye movement was replaced by a number of smaller saccades, which later gave way to a smooth slow eye movement, between the fixation points. This phenomenon would appear to be similar to the described by Col Frohlich.

FRÖHLICH. I am very grateful for this remark. We found the same effect in the electronystagmographic records of subjects who fixated sequentially on points with a 20° separation.

ANALYSIS OF THE VESTIBULO-OCULAR COUNTERROLL REFLEX IN PRIMATES*

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SUMMARY

The vestibulo-ocular reflex manifest by counterroll was used to determine the response dynamics of the vestibular system and alterations in these dynamics subsequent to +Gx acceleration exposure. Six rhesus monkeys were tested before and after acceleration exposure to determine if significant changes had occurred in the vestibulo-ocular counterroll reflex. The tests consisted of constant speed rotation, pendular oscillations and multiple sine wave oscillations about the subject's cyclopean axis. Ocular counterroll was recorded using a linear resolver mechanically fixed to the monkey's eyeball. The data collected was analyzed by use of the Fast Fourier Transform. This work demonstrates that there is no significant decrease in the system gain with inputs up to 1 Hz; the observed phase lag can be accounted for by a time delay of approximately 0.2 seconds, and there is no significant response alteration caused by acceleration loading up to 75 +Gx.

INTRODUCTION

Recent emphasis on the interaction of vestibular function and human operator performance has demonstrated a critical need for a mathematical analysis of the vestibular system. The primary purpose of our work is to define the transfer function characteristics of the vestibular system in order to predict vestibular influence on man/machine control performance.

Previous studies have indicated that the ocular counterroll reflex is a measure of vestibular function and that both the semicircular canals and otolith organs are involved. In order to assess the influence of the semicircular canals and otolith organs on human operator performance, a quantitative description of these systems is necessary. It has been postulated that otolith organs act as linear acceleration sensors and that the semicircular canals act as angular acceleration sensors. Their functions may therefore be separated by correlating the smooth pursuit component of ocular counterroll with the linear acceleration portion of the forcing function and by correlating the rotary nystagmus portion with the angular acceleration component of the forcing function.

Parker, et al, (1) have reported otolith organ damage in guinea pigs exposed to acceleration levels as low as 12 +Gx. This suggests that commonly used experimental acceleration levels might cause functional otolith organ damage. Monkeys were exposed to +Gx acceleration (12.5 to 75 +Gx) in an attempt to alter vestibular function. Using ocular counterroll as an indicator of vestibular function (specifically otolith organ function), counterroll measurements were made before and after +Gx acceleration.

METHODS

Experiments designed to yield baseline data were conducted with twelve rhesus monkeys. Direct measurements of eyeball counterroll relative to the median sagittal plane were made by using a custom fitted contact lens coupled to a linear transformer. To eliminate slippage, the lens was sutured to the eyeball using two sutures placed at the medial and lateral limbus (Figure 1). During suture placement, the monkey was under metered halothane anesthesia. The sutures are passed through holes drilled in the lens, the lens is next inserted and the sutures tied. Subjects were immobilized in a restraint chair mounted on a controlled motion platform. The contact lens was then coupled via a flexible shaft (Figure 2) to a linear transformer mounted on the motion platform. During the experiment, a topical anesthetic was administered to minimize discomfort. The other eye was covered and the experiment conducted in near darkness.

The subjects were exposed to three types of motion input about the cyclopean axis: constant speed, pendular oscillations and multiple sine wave oscillations. The position of the subject's median sagittal plane relative to the local gravity vector was measured by means of a potentiometer connected to the drive shaft of the rotating platform. We define the potentiometer output as θ_c. To facilitate viewing of the time traces for positive potentiometer values, counterroll output from the linear transformer was defined as positive. Constant speed rotations (0.05-1.0 Hz) were used because they afford linear acceleration inputs with no angular acceleration component. For this input, the acceleration, As, is given by $As = g\sin\theta_c$, where g is 980. For constant speed input, the potentiometer reads from $\pm 180°$ to $\mp 180°$ and resets at the null point on the winding (Figure 3). Pendular motions ($\theta_c \pm 90°$, 0.05-0.5 Hz) were also used.

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*The experiments reported herein were conducted according to the "Guide for Laboratory Animals Facilities and Care," 1965, prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences - National Research Council.
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The research reported in this paper was conducted by personnel of the Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, and the Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio 45433.
This paper has been identified by Aerospace Medical Research Laboratory as AMRL-TR-71-59.

The linear acceleration component of this input is much like that for constant speed rotations with the addition of a sinusoidal angular acceleration component ($\ddot{\theta}_c$). Since this input is a combination of linear and angular accelerations, the response to both can be separated, assuming linearity. The third input was random appearing pendular motions designed to produce a nonpredictive input. The summation of five sine waves (0.05-0.6 Hz) was used as the nonpredictive forcing function to the motion platform. Input (θ_c) and output (eye position) signals were recorded on analog tape and subsequently digitized and recorded on digital tape for analysis on an IBM 360 Model 40 graphics computer. The Fourier Transforms of the input and output time records were approximated using the discrete Fourier Transform implemented by the Cooley-Tuckey Algorithm or Fast Fourier Transform. From the transform values, the power spectral densities (PSD) for the input and output signals were computed.

Six of the twelve rhesus monkeys for which baseline data was collected were exposed to high +Gx acceleration levels. Each monkey was anesthetized, placed in a restraint device and exposed to various acceleration profiles (Table 1). Ocular counterroll response of all six subjects was measured at different times ranging from one day to several months after acceleration exposure.

RESULTS AND DISCUSSION

Normal counterroll response to constant speed rotation consists of an initial nystagmus (input onset) followed by a smooth sinusoidal eye movement and concludes with a post-rotary nystagmus (input cessation, Figure 3). Relating the smooth portion of the response to the linear acceleration input for various speeds yields a dynamic model of the linear accelerometers. The dynamic response of the angular accelerometers can be derived by application of the Laplace transform to a comparison of the slow phase component of the post-rotary nystagmus with the change in angular velocity of the chair.

Response to pendular motions is similar to that caused by constant speed rotation with the inclusion of a fast phase component throughout the trace (Figure 4). Portions of the response which generally are in the direction of the stimulus are called slow phase components (SPC). Those components which are either opposite in direction to the SPC or which have significantly greater slope than the SPC are defined as fast phase components (FPC).

The FPC of the counterroll response is believed to be a resetting action caused by velocity and/or contraction limits inherent in the ocular muscles. Removal of this resetting motion and cumulation of the SPC yields the commanded eye motion. This motion represents ocular response to vestibular output caused by both angular and linear acceleration inputs. It is this cumulative eye motion which we wish to use to study the dynamics of the vestibular system. Removal of the FPC and cumulation of SPC for a response to a pendular motion is shown in Figure 5. The method used to remove FPC is structured around an algorithm suggested by Tole and Young (2). From Figure 5 it can be seen that cumulation of the slow phase position results in approximately 80° of commanded eye motion. From this cumulative slow phase position and the information derived from constant speed rotation, the response to linear acceleration can be removed to yield the counterroll response to angular acceleration.

A time trace of the counterroll response to the third input, multiple sine waves, is shown in Figure 6. Though it is difficult to assess the degree of correlation between input and output signals from this illustration, preliminary frequency analysis indicates that the fundamental frequency components of the counterroll response (output) occur at the same frequencies as that of the input. This is also true for constant speed rotation and pendular motion (Figures 7, 8, and 9).

From the constant speed input and output transforms, phase and amplitude ratios can be computed and a Bode diagram constructed for baseline data. This work is presently being carried out and should yield a model for the linear accelerometers. Some of the data analyzed thus far is plotted in Figure 10. This data indicates that there is no significant decrease in amplitude ratio with increasing frequency up to 1 Hz. The observed phase lag shown in the lower portion of Figure 10 can be accounted for by a time delay of approximately 0.2 seconds.

The cumulated slow phase counterroll due to pendular motion input represents a response to both linear and angular acceleration. Using the model for the linear accelerometers, the response due to linear acceleration can be removed. From the remaining counterroll response and the angular acceleration input, another Bode diagram can be constructed to give the dynamic characteristics of the angular accelerometers about the cyclopean axis.

The pre and post acceleration counterroll responses appear qualitatively the same and the Gx exposure levels used seem to have no demonstrable effect on the functional characteristics of the vestibular organs. Phase and amplitude ratios of the counterroll response to constant speed rotations after acceleration exposure do not vary significantly from values before exposure. In addition, none of the monkeys exposed to +Gx acceleration exhibited behavioral abnormalities symptomatic of vestibular end organ damage. Preliminary temporal bone examination suggests that these levels of acceleration do not result in gross displacement of otoconia.

Figure 1. Custom fitted contact lens about to be inserted. Sutures have been placed through limbus and lens. Note how the stalk is integral with the contact lens.

Figure 2. The monkey has been packed in the restraint chair to eliminate head movements. The flexible shaft of the linear transformer has been coupled to the contact lens stalk to record torsional eye movements.

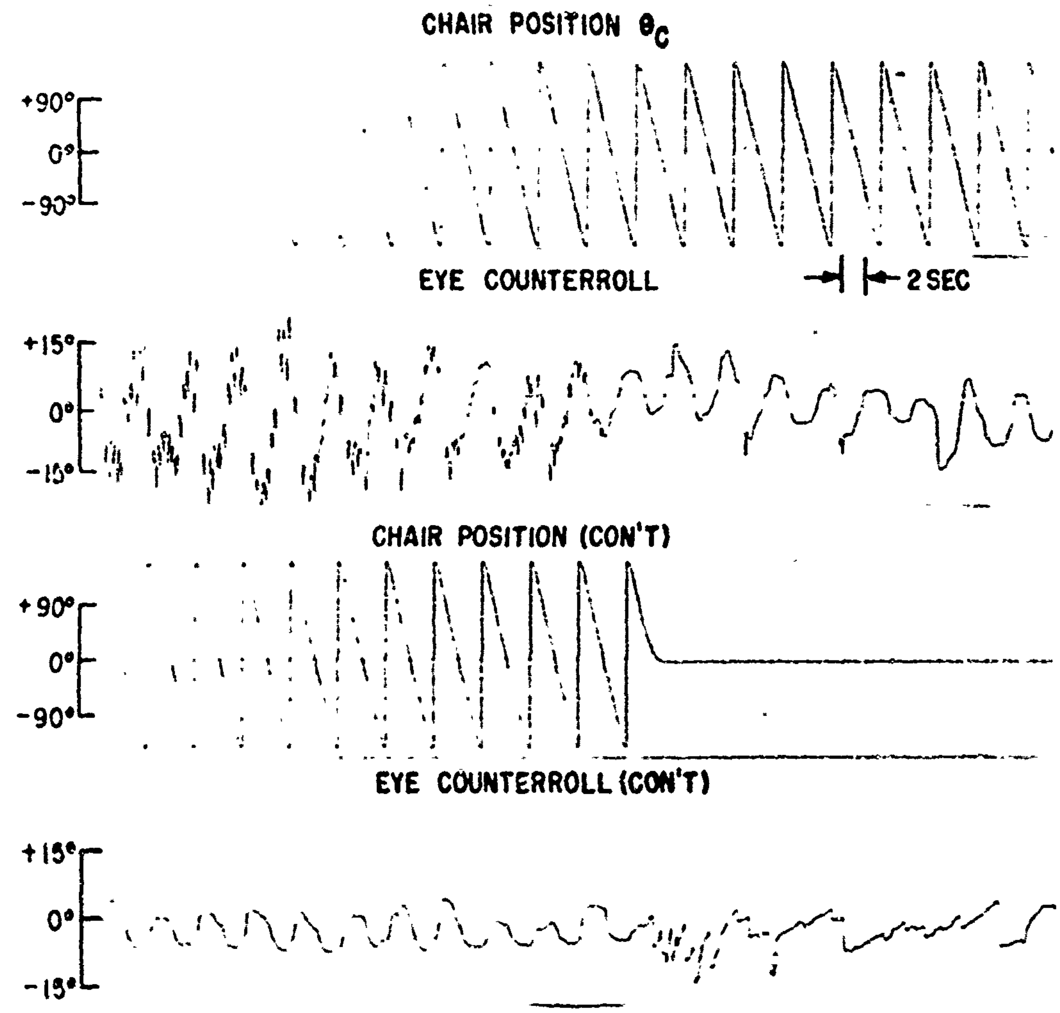


Figure 3. Counterroll response to a .25 Hz constant speed input. Note nystagmus of eye counterroll during the initial portion of rotation followed by a smooth sinusoidal motion. Then as the chair motion goes to zero, note the post-rotary nystagmus in the eye counterroll response.

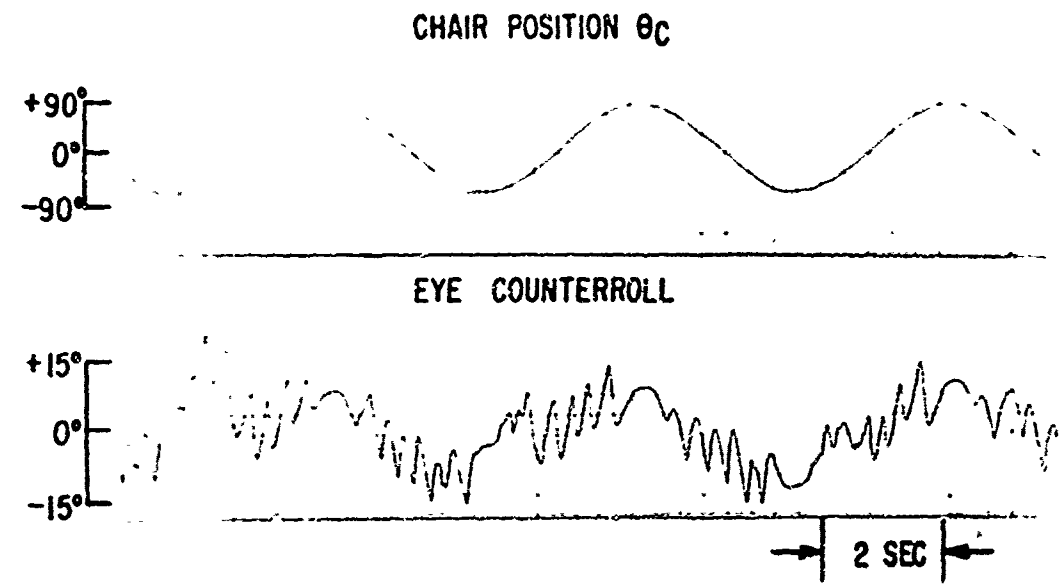
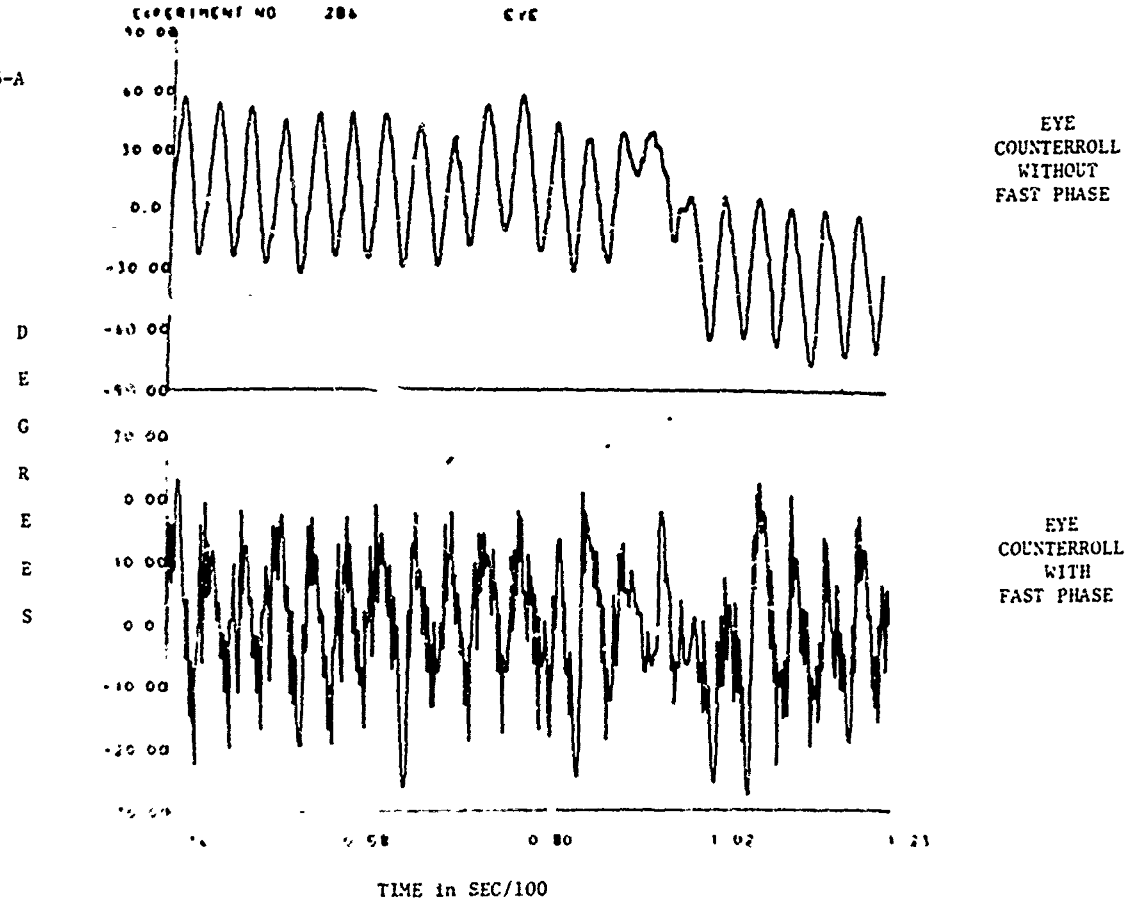


Figure 4. A portion of eye counterroll response to a pendular chair motion of 0.. Hz. These torsional eye movements exhibit typical slow and fast phase motions (nystagmus).

5-A



5-B

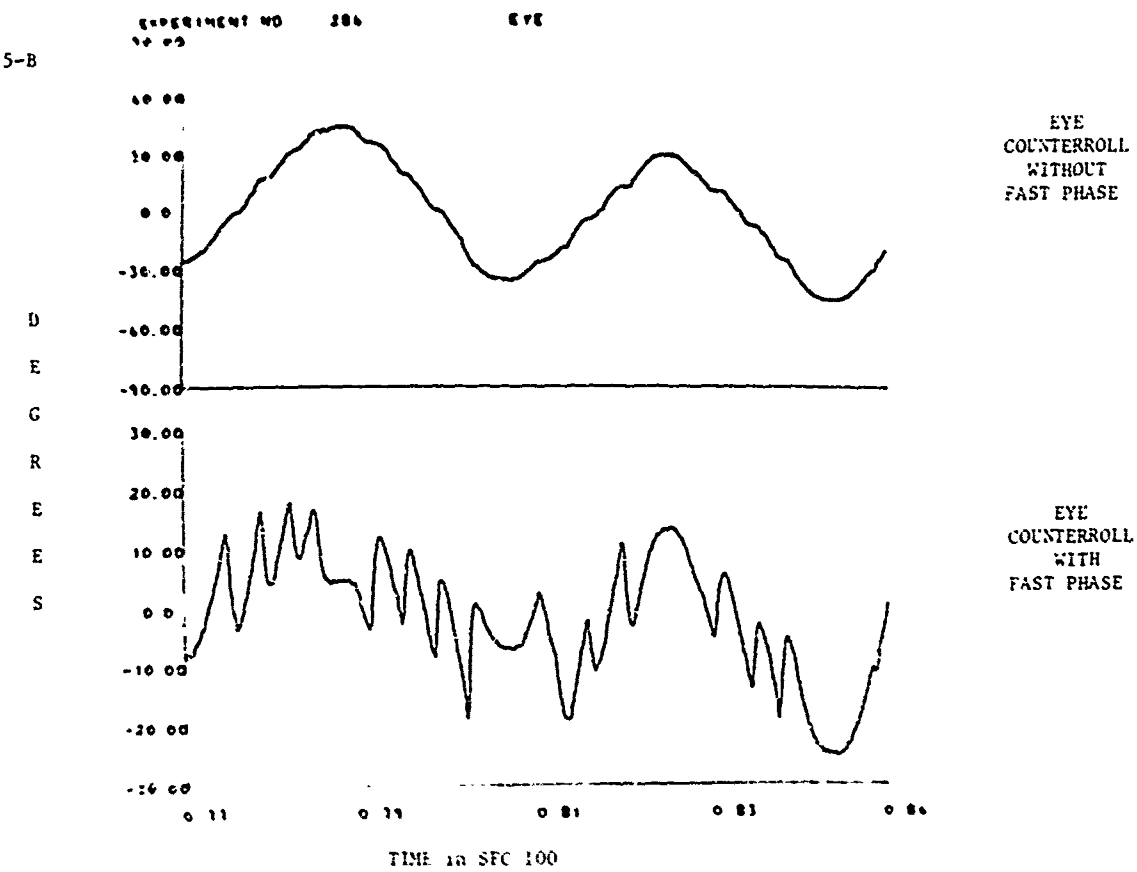


Figure 5. Shown in the lower trace of Figure 5-A is the recorded eye counterroll response to an 0.2 Hz pendular motion. The upper trace of Figure 5-A is the cumulative slow phase response with the fast phase portions removed. Figure 5-B is an expanded segment of 5-A.

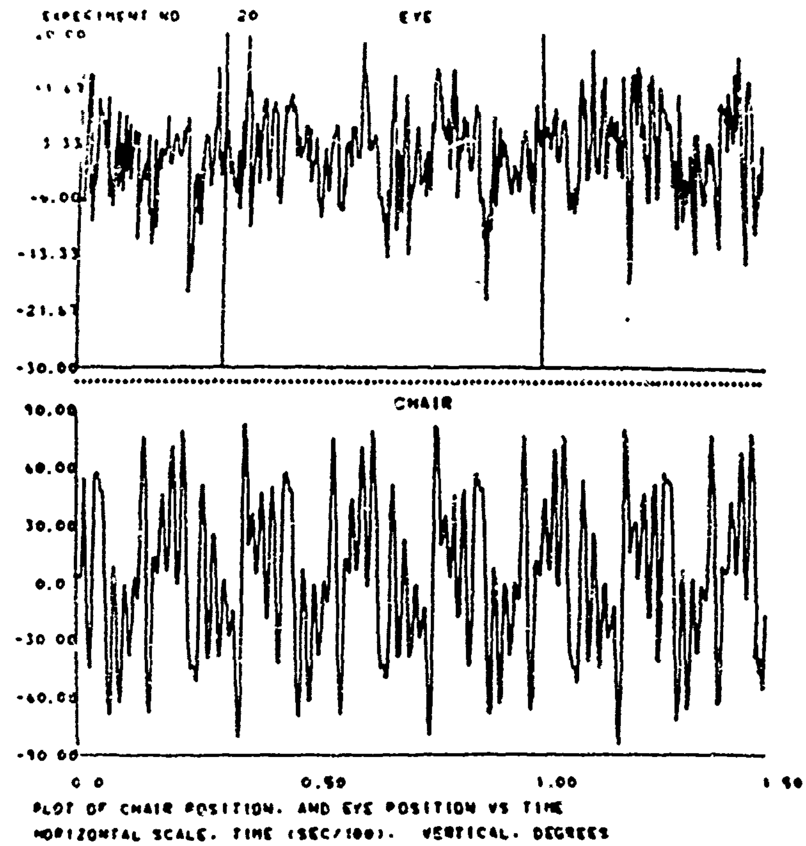


Figure 6. Eye counterroll response to a multiple sine wave motion input. Included within the eye trace are two vertical lines (at approximately 30 and 100 sec). It is over the range delineated by these lines that the Fourier Transform and PSD shown in Figure 7 were calculated.

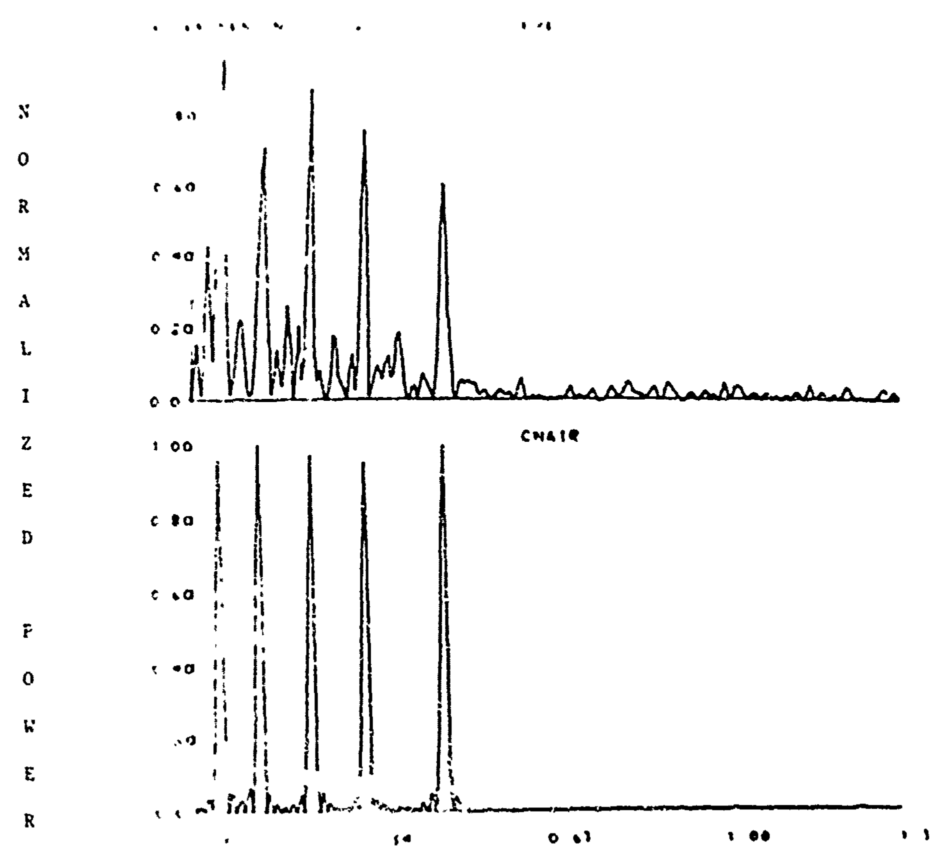


Figure 7. Power spectral densities (PSD) for eye counterroll and chair motion resulting from a multiple sine wave forcing function. Both traces have been normalized to their maxima.

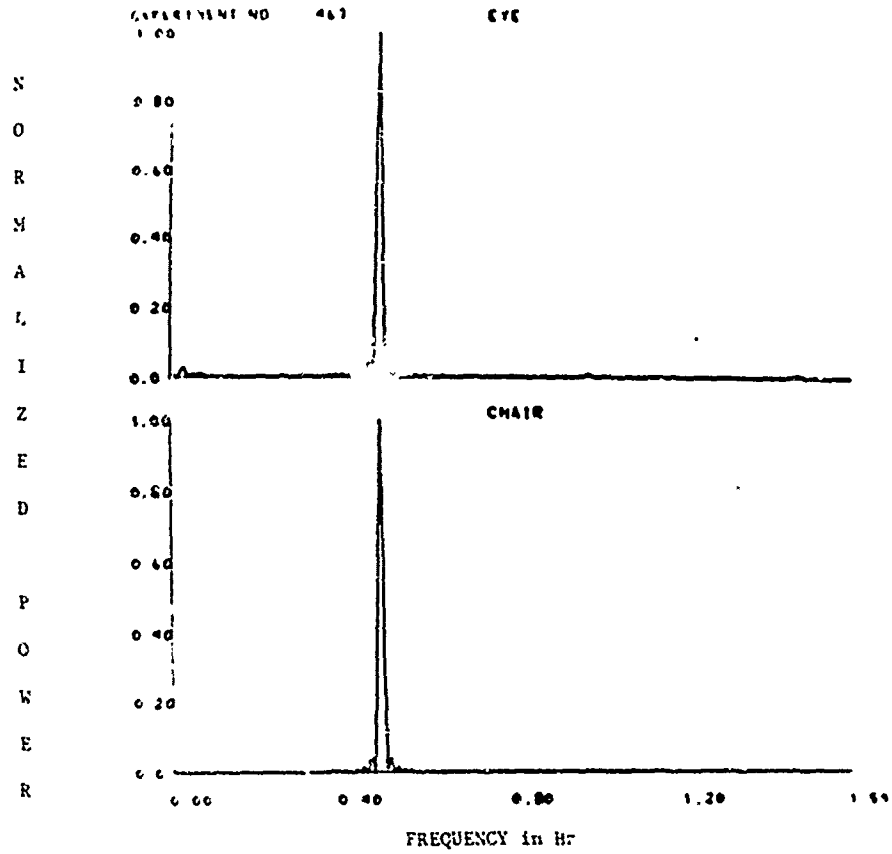


Figure 8. Power spectral densities for a constant speed rotational test of 0.483 Hz. Both traces have been normalized to their maximum values. For this test, the amplitude ratio at .483 Hz was -46.97 db and the phase was -41.79°.

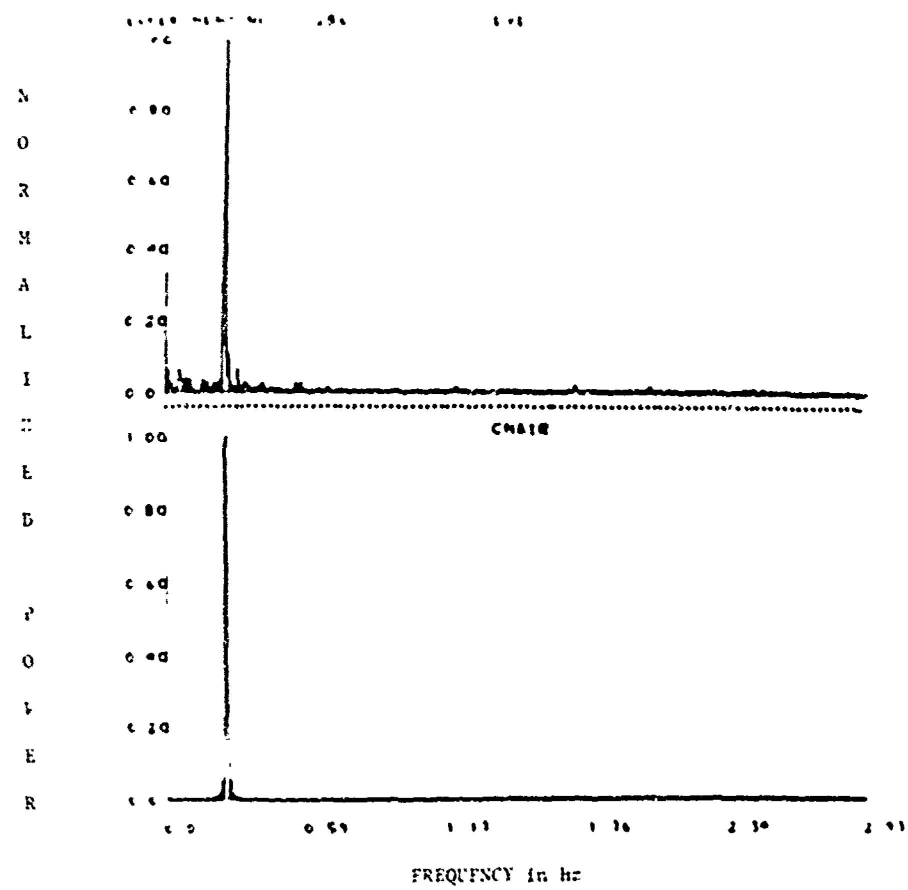


Figure 9. Power spectral densities for a pendular motion of .244 Hz. Both traces have been normalized to their maximum values. At .244 Hz, the gain was -39.3 db and the phase was +25.8°.

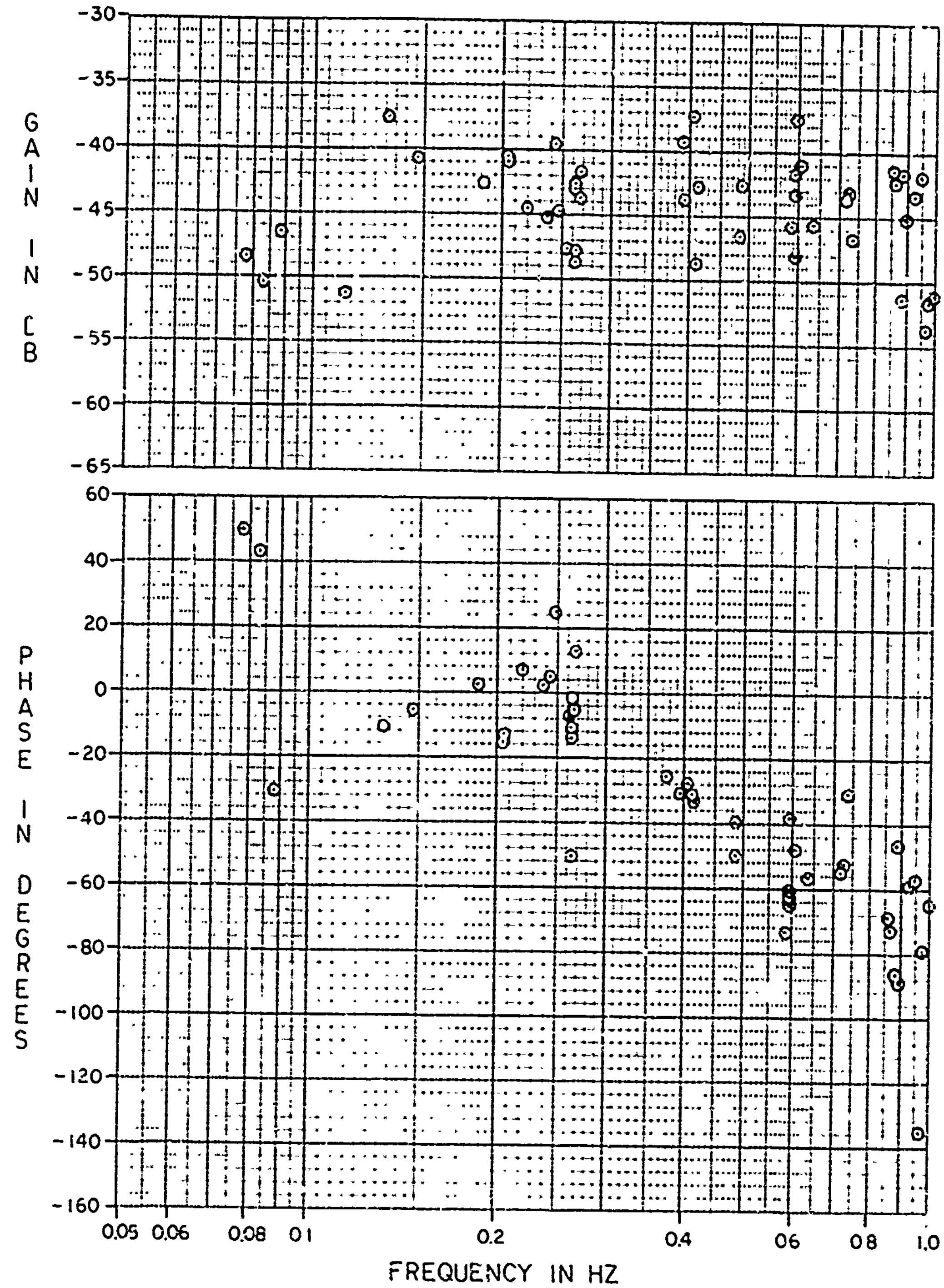
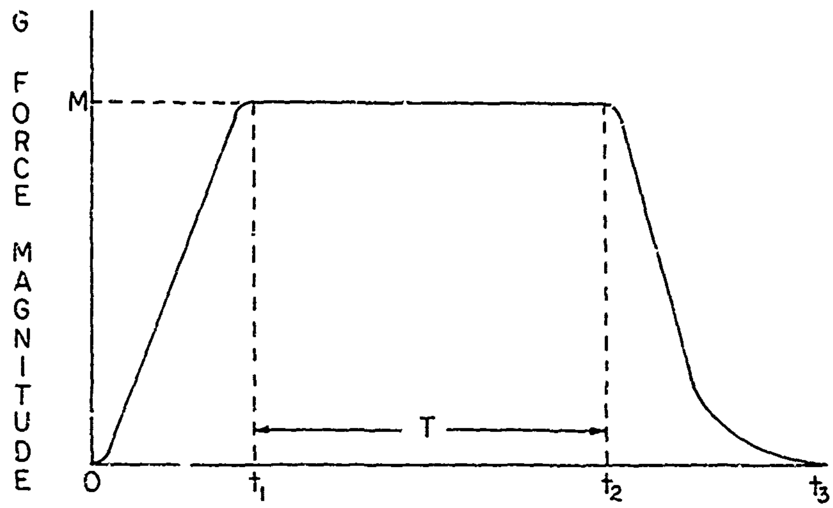


Figure 10. Gain and phase plot constructed from constant speed baseline data.

Table 1. Table of G-Exposure Profiles



Monkey	Date	t_1 (Sec)	t_2 (Sec)	t_3 (Sec)	T (Sec)	M (Gx)
M76	6 Nov 70	26	61	70	35	50
M76	13 Nov 70	37	67	85	30	60
M76	30 Nov 70	49	94	117	45	70
N88	10 Dec 70	48	101	123	55	70
080	18 Mar 71	11	71	78	60	12.5
092	18 Mar 71	19	79	89	60	25
20	18 Mar 71	51	81	104	30	75
P42	18 Mar 71	10	70	76	60	12.5

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2. Tole, John R. and Young, Laurence R. MITNYS: A Hybrid Program for On-Line Analysis of Nystagmus, Cambridge, Massachusetts, Man-Vehicle Laboratory, MIT, Unpublished Report.

ACKNOWLEDGEMENT

The authors would like to thank Lt Robin Pearse, presently assigned to CINCNORAD(NPCP-MJ), for his programming assistance on this project.

DISCUSSION

BENSON. Your Bode plots, which presumably reflect the dynamics of the otolith/eye control system, show only phase lag at the higher frequencies (0.1-1.0 Hz). Yet in experiments carried out on human subjects exposed to a rotating specific force (as in your experiments) we have found that over a wide range of frequencies judgement of position was phase advanced. Can you reconcile these subjective data with your objective findings.

JUNKER. Not really. But I would like to say that other data collected by Kellogg, who used a photographic technique with human subjects, showed phase lag at frequencies above 0.1 rad/sec. In addition I seem to remember subjective data collected by Meiry & Young, during linear sinusoidal oscillation, also showed lag with increasing frequency.

MALCOLM. Is it possible that the lag term in your data could be due to the extra mass of the lens-stalk transducer system? It would appear that these components are quite massive.

To the remarks of Dr Benson, I can add that it is quite simple to fit the data obtained by Lowenstein & Roberts for the gravity receptors in the Ray by postulating a phase advance model.

JUNKER. We have calculated that the torque required to operate the linear transformer is insignificant. As you probably know, measurements of torsional eye movements are usually either very time consuming (photographic technique) or very expensive (TV and computer analysis). Our technique is neither expensive nor time consuming. Torsional eye movements were measured by Kellogg and also Replogle & Kabrisse many years ago utilizing a photographic technique. They used land-marks on the iris so there was no inertial loading of the globe. Their results (though fewer and limited) also indicated increasing phase shift as a function of time as does ours. Let me add that at low frequency (below 0.2 Hz) the stimulus is such that the subject moves around more and variability is increased. At low frequencies we found both lead and lag, thus our model really holds only for the higher frequencies.

Two Specific Kinds of Disorientation Incidents: Jet Upset and Giant Hand

by

R. Malcolm and K.E. Money

Abstract

In certain circumstances (instrument flying conditions and severe turbulence), an inappropriate pilot input to aircraft controls leads to a dangerous nose down attitude of the aircraft. There have been something in excess of 26 of these "Jet Upsets". In similar circumstances, there have been a few reports of what can be called the "Giant Hand" phenomenon, in which the pilot reports that the aircraft controls are forced into an extreme position and held there as if by a giant hand. Precipitating circumstances and underlying mechanisms of these two kinds of incidents are discussed, and some unpublished experimental observations are presented.

INTRODUCTION

Several kinds of pilot disorientation in flight, such as the Coriolis disorientation, the "leans", and the sensation of climbing which accompanies forward acceleration, are well known by scientists and by pilots. Pilots are advised that when they become aware of any of these kinds of disorientation they should fly (as always) by visual reference, usually by visual reference to the aircraft instruments. The instruments should be cross checked and believed and made to indicate the desired attitude of flight regardless of continuing or resulting sensations that the aircraft attitude is not what the pilot wants. This advice has passed the test of time and it is a correct and vital part of a pilot's instruction in aviation medicine. Nevertheless, this advice as usually given is incomplete for dealing with two less common and less well known kinds of disorientation which are described below.

THE JET UPSET PHENOMENON

"On February 12, 1963, a Northwest Airlines Boeing 720B aircraft, after taking off from Miami International Airport in Florida, flew into thunderstorm turbulence at about 19,000 ft altitude and crashed, killing all of the passengers and crew members on board" (Hitchcock and Chambers 1965). This accident is considered the first caused by turbulence in a swept wing jet transport aircraft, and probably it is also the first case of "jet upset" in a transport aircraft. A jet upset involves a jet aircraft which, without the pilot intending it and without structural failure, gets into a severe nose down attitude and loses a lot of altitude. After upset, recovery to level flight is difficult and in many instances the aircraft crashes into the ground.

From flight recorder data, and from crew reports in those cases in which the aircraft was saved, it has been learned that the upset syndrome often includes:

(1) instrument flight conditions (no visual horizon)
(2) severe turbulence
(3) pilot inability to read his flight instruments for a period of time
(4) a sensation in the pilot that the aircraft has pitched up dangerously, even to the point of pitching up into a half loop (this sensation is erroneous)
(5) a pilot control input which causes the nose of the aircraft to be lowered dangerously
(6) difficulties in raising the nose of the aircraft back to level flight (these difficulties can involve mistrim, "tucking", stalling of the horizontal stabilizer drive, and control column forces of over 200 pounds).

In some cases jet upset has been initiated by failure of the automatic pilot.

There are records (Bisgood and Burnham 1965, Buley 1967, Soderlind 1964) of 26 jet upsets in commercial airliners in less than 10 years, and records of 12 similar upsets in propeller driven aircraft. There are probably additional (unpublicized) incidents involving commercial aircraft and further additional incidents involving military aircraft. It seems clear that some of the upsets have occurred without gross human malfunction (for example, 2 upsets which were initiated by failure of the autopilot) but in many other instances human malfunction is well documented. Pilots have reported that they were disoriented and that they were unable to see the instruments.

In February of 1970 a commercial DC8 aircraft was descending in cloud when severe turbulence was encountered, including negative G forces. The captain of the aircraft reported later that after a brief period of this turbulence the instrument panel became blank and he had the sensation that the aircraft had done a half loop and was on its back. He reported pushing forward on the control column. The feeling of being upside down was, he said, overpowering for what seemed like several minutes. He was about to give control to the first officer when the first officer said "Christ, we're upside down". The captain then decided that there was nothing to be gained by handing over control to someone equally disoriented. The second officer meanwhile was aware of negative G, he saw that the captain was holding the control column forward and he saw the artificial horizon which was indicating a nose down attitude. When the first officer said "Christ, we're upside down" the concerned second officer said "No we're not. Pull it up, pull it up". It is not clear whether the captain was able to act on the advice immediately or whether he waited until he could see the attitude instruments. The first officer was apparently the first to start pulling on the control column, and then the captain joined him and together they pulled the nose up, with encouragement from the second officer who was saying "A little more, a little more". When the captain was able to see the instruments again, the

aircraft was in relatively smooth air, but still in cloud. This is perhaps a typical jet upset incident, except that it can be considered unusual (Soderlind 1964) that recovery was effected without the establishment of visual outside reference.

Aside from the engineering and procedural aspects of turbulence penetration and aside from the mechanics of aircraft controls which are effective in pulling up from a high speed dive (two important parts of the problem) there are also several human factors parts of the problem which require action. First, a study should be undertaken to design and build the best seat for permitting vision during turbulence and vibration. This is clearly an important problem since pilots have reported incidents even during clear air turbulence when the instruments were not readable. It is possible that in the DC8 incident described above the second officer was able to read the artificial horizon because his seat cushion or springs oscillated him differently during the vibration, either because his seat or his body weight was different. Second, the face of the artificial horizon should be increased, perhaps doubled, in size to make it easier to see. There seems to be no compelling reason for it to be only three inches in diameter. The colouring and lighting of this instrument could also be optimized for turbulence penetration. Third, pilots should be given special instruction concerning disorientation in the jet upset situation.

Pilots should be told that in turbulence, particularly when visibility is restricted by clouds or by darkness, it occasionally happens that the pilot experiences an overpowering sensation (initiated by his body's inertial receptors) that the aircraft is pitching up, even up into a half loop. If such a sensation is experienced the pilot must remember that it might be a false sensation and he must not make any heroic control movements before checking the artificial horizon. The advice to the pilot thus far is essentially the classic "believe your instruments" but for this situation it goes further. The pilot should be told that if he tries to check the artificial horizon but cannot read it, the aircraft controls should be left neutral until the artificial horizon can be read and it should be remembered that many pilots in this situation have pushed the nose down dangerously far. It is exceedingly dangerous to use nose down trim in this situation. When the pilot can read the instruments he should believe them and use the aircraft controls to make them read correctly regardless of sensations concerning orientation. It should be remembered that in severe turbulence the only instrument which always gives correct attitude information (disregarding malfunctions) is the artificial horizon (Soderlind 1964, Buley 1967, Hitchcock and Chambers 1965).

THE GIANT HAND PHENOMENON

Three aircraft incidents have been brought to the attention of the authors wherein the pilot has lost control because the control column has been apparently pulled forward or sideways despite all efforts on the part of the pilot to restrain it. The initial reaction has been to assume that some control malfunction has precipitated this event; however, further evidence reveals that this is not the case. In one instance (King 1962) "the pilot (a medical doctor) felt the control column being pulled from him as though by a "giant hand". He tried to center the control column by pulling on it with both hands and both knees, but with no success. Realising that he was disoriented, he realeased his grip on the stick, and watched while it floated back to the central position by itself. For several minutes thereafter he was able to control the aircraft only by grasping the control column with thumb and forefinger. He was suffering from a subjective impression that the aircraft was in a steep bank to the right, and whenever he closed his whole hand over the stick it appeared to be thrown forceably over towards the left".

In another instance, the assumed control malfunction caused the aircraft to drop its nose while at very low altitude, shortly after the pilot switched off the afterburner. After the pilot ejected, the aircraft continued on for a considerable distance before impacting the ground at a shallow angle.

The third case occurred during a dive bombing attack, when the pilot found that he could not pull out of the dive even by using both hands and his leg. The stick was being firmly held well forward and to the left, and so he pushed it further forward and eventually recovered control by doing an outside roll.

Conditions Leading to Onset

There are four conditions common to all of the above three incidents which might be necessary for the 'Giant Hand' effect to take place. A state of anxiety or mental arousal seems to have been prevalent for some minutes prior to the incident. The control of the aircraft has involved a motor task of one or both hands. Immediately prior to the event, the pilot has been distracted from the immediate task of controlling the attitude of the aircraft. The resultant gravity vector has been rotated forward (as during deceleration), or the pilot felt that he was pitched forward, as when diving or during some types of cross-coupled head movements.

Experimental Evidence

A preliminary experiment to test these conditions was performed in a crude flight simulator mounted on the back of a 2½ ton truck. The simulator could be manually moved to any position from 45° nose down to 45° nose up and 45° of roll in either direction. The subjects sat in an aircraft seat, fully harnessed, and enclosed by black shrouds mounted on frames affixed to the seat. The seat itself was mounted on gimbals to permit the lattitudes of motion described above. The subject held a passive 'control' stick in his right hand, and the position (fore/aft, left/right) of the stick was indicated to the experimentors on two scales outside the shrouds. The attitude of the simulator was altered by an assistant using handles affixed to the gimbals, in response to the indicated position of the control stick.

The subjects were instructed to fly the simulator at what they perceived was a 15° nose up attitude, wings straight and level, while the truck accelerated from 0 to 50 miles per hour. Upon

reaching this speed, the subjects were told to fly straight and level, when they were surprised with a sudden deceleration caused by a one second application of the truck's brakes.

Of the 20 subjects tested in this ma..ner, two exhibited wh.t could be classifi.d as a giant hand effect. They both felt as though the stick were being wrested from their hands, ' .h became very agitated and thought that they had tipped over. One man insisted that he had hit his head on the floor of the truck, although this was obviously an impossibility.

A Possible Mechanism

The condition of anxiety is known to increase the level of activity of the Reticular Activating System in the mid-brain. The rotating gravity vector increases the activity in Deiter's nucleus. The motor task of gripping the stick increases the level of activity in Sherrington's final common pathway in the spinal column. A sudden distraction from the control task possibly releases pyramidal tract control. All of these conditions are known to lead to or increase an existing state of spasticity Brain (1927) found in hemiplegic patients who are tipped forward from the upright position, that the paralyzed arm which is usually flexed becomes rigidly extended and supports the body in anthropoid (quadruped) fashion.

It is proposed then, that the Giant Hant phenomenon described above is the result of a postural reflex, an uncontrollable reflex response to the psychological and physiological conditions affecting the pilot prior to and during the incident. The pilot beli' 'es he is pulling back on the control column, when in fact he is actually pushing it. The problem is compounded by the fact that a forward motion of the control column causes the nose of the aircraft to drop and the aircraft to enter a dive, causing the gravity vector to rotate further forward creating a condition of positive feedback. It is not clear whether an erroneous sensation of aircraft attitude is necessary for the occurrence of the Giant Hand phenomenon, and therefore disorientation as strictly defined may not be involved.

Further experiments are being conducted by the authors in an attempt to better understand this phenomenon. Until the problem is better understood, pilots should be told that probably the best way to cope with an occurrence of the Giant Hand 'enomenon is to open the control loops by either letting go of the stick and switching to a thumb and forefinger grasp, or by pushing the control column in the direction of the pull. Obviously the manner selected will depend on the particular circumstances in which the pilot finds himself.

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DISCUSSION

VIOLETTE. I am in agreement with the explanation of the 'Giant Hand' phenomenon which you have suggested. However, another mechanism is also possible. Movement of the head with respect to the neck can bring about changes in the distribution of muscle tonus and produce extensor movements. Thus sharp involuntary movement of the head of the pilot may be an explanation of the phenomenon [illegible] described; for example, turning the head to the left would engender contraction of exte[illegible] muscles on th[illegible] right side of the body.

MALCOLM. The reflexes you describe can certainly be elicited from a 'spinal animal' ie an animal with high transection of the spinal cord. However, everyday experience tells us that this does not seem to occur in a normal, healthy, conscious humans. The mechanism I have postulated effectively produces this 'spinal condition' for a short period of time, enabling these low level spinal reflexes to take over, and remain effectively beyond conscious control. In the three cases discussed, it is unlikely that the pilot's head was turned away from straight ahead position for any length of time because they all could see their hands. The other possibility is that their heads were being thrown about by the violent manoeuvering of the aircraft, but this would, by your explanation, produce a complex pattern of movement of the limbs and not the steady, repeatable, consistent push encountered by these subjects.

DOBIE. There would appear to be little doubt that the 'giant hand' phenomenon was associated with a panic state, but is it not possible that the limb movements were a manifestation of 'carpo-pedal spasm' brough about by hyperventilation in this panic state?

MALCOLM. This explanation is quite possible, and cannot be discounted. However, in the incident described by Wing Commander King he was able to let go of the stick, where upon it 'floated back to centre' from its rather extreme position. Upon grabbing the stick again, the reflex reaction occurred again. This sequence may not be possible with such a spasm.

BENSON. The 'giant hand' phenomenon which you have so graphically and clearly described is a motor rather than perceptual phenomenon. Thus although associated with profound motion stimuli it is not by definition 'spatial disorientation', although it may be a concomitant of this perceptual disturbance.

MALCOLM. Yes I agree. The 'giant hand' is primarily a motor rather than a sensory phenomenon, though there is, in part, illusory perception of movemenc of the limbs and the forces responsible for this motion.

AL DISORIENTATION AND THE 'BREAK-OFF' PHENOMENON

by

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SUMMARY

Out of 72 aircrew referred for clinical assessment because of 'disorientation in flight', 23 pilots described incidents in which they experienced feelings of unreality and detachment. These commonly occurred during monotonous phases of flight in conditions where external visual orientation cues were restricted. In 19 pilots of fixed wing aircraft the perceptual disturbances characteristic of the 'break-off' phenomenon occurred when flying at altitudes in excess of 30,000 ft, but 4 helicopter pilots had comparable sensory disturbances at 500-10,000 ft. In all but 2 pilots the dissociative sensations were coupled with illusory perceptions of aircraft attitude and motion, though only in 7 pilots was there a qualitatively false perception of aircraft orientation. Evidence is presented which suggests the 'spatial disorientation' occurring as a concomitant of 'break-off' was caused by minor degrees of vestibular asymmetry. All the referred aircrew found the derealization and other sensations of 'break-off' disturbing. The high incidence of anxiety reactions supports the view that in susceptible individuals 'break-off' can be both a precipitant and a manifestation of anxiety neurosis.

The perceptual problems experienced by pilots in determining the attitude and motion of their aircraft has been recognised since the early days of powered flight. The limitations of man's perceptual abilities in the environment of flight are now well appreciated and the mechanisms of many of the illusory perceptions engendered by angular and linear accelerations are understood.(1,2,3,4) Nevertheless a number of aircrew experience perceptual disturbances in flight which cannot readily be accounted for on the basis of the physiological limitations of sensory function or of disturbance of normal function by disease processes. These errors or disturbances of perception though labelled collectively as 'disorientation' are frequently not associated with illusory perception of the attitude or motion of the aircraft; in other words there is no 'spatial disorientation', if this term is restricted to those incidents in which the aviator fails to appreciate correctly the attitude, position and motion of his aircraft with respect to some external reference such as the earth's surface.

The restrictive definition of 'spatial disorientation' given above, refers of course to only one facet of perceptual processes underlying both spatial orientation and disorientation in flight. Few would disagree that it is the most important, for if the pilot's perception of the orientation of his aircraft is incorrect then his control of its orientation is also likely to be incorrect and the safety of aircraft and occupants is jeopardised. As Fig.1 illustrates, the aviator's ability to determine the spatial orientation of his aircraft is interdependent not only upon his ability to orientate himself correctly with respect to earth datum but also upon his correct perception of the orientation of his own body with respect to the aircraft. Because the sensory cues which allow the pilot to determine his orientation to the aircraft are both numerous and harmoniously co-ordinated, the perceptual linkage between pilot and aircraft is strong. Accordingly it is relatively easy for him to orientate himself with respect to the aircraft - indeed so easy that the importance of the perceptual linkage, though clearly recognised by Clark & Graybiel (1), is frequently neglected in discussion of the mechanisms underlying the illusory perception of aircraft motion. For example in many disorientation incidents the aviator has false or inadequate information from vestibular and other mechanoreceptors which give rise to a false sensation of the pilot's position or attitude in space. But because of the firm perceptual bond between pilot and aircraft the motion sensed by the pilot is perceived as that of the aircraft.

Spatial disorientation, characterised by a false perception of aircraft attitude or motion, is more likely to lead to an aircraft accident, than those perceptual disturbances which disturb the aviator's orientation of self with respect to the aircraft, or of self with respect to the earth datum. Yet it has been our experience in the Royal Air Force that in the aircrew who were referred for specialist assessment, because of 'disorientation' in flight, disturbances of the aviator's perception of his orientation with respect to aircraft and ground were nearly as common as those in which there were illusory perceptions of aircraft orientation.

Over the last ten years 72 aircrew were referred by the Consultant in Neuropsychiatry of the RAF Central Medical Establishment for special investigation of 'disorientation' at the Institute of Aviation Medicine. Of these, 27 aircrew had false perception of aircraft orientation, 23 had disordered perception of their relationship to aircraft or ground, and 11 experienced both types of disorientation. It must be pointed out that these figures do not reflect the incidence of these different types of disorientation in the normal aircrew population or indeed the distribution of incidents which are reported to Station Medical Officers. Rather they tend to emphasise those incidents which belie a simple explanation in terms of physiological mechanisms or where there are associated psychiatric problems.

Although the in-flight incidents reported by this group of aircrew covered a wide variety of disordered perceptions, an altered awareness of the aviator's relationship to the aircraft or to the earth's surface was described by 34 of the individuals examined. Typically the sensations were a feeling of detachment and isolation, frequently associated with flight at high altitude during relatively undemanding phases of the flight. Both the subjective symptoms and the flight environment in which the incidents occurred, corresponded to those described by Clark & Graybiel (5) and named by these authors the 'break-off' phenomenon. While accepting the descriptive utility of this term it must be recognised that comparable dissociative symptoms occur in situations other than those of flight where there is

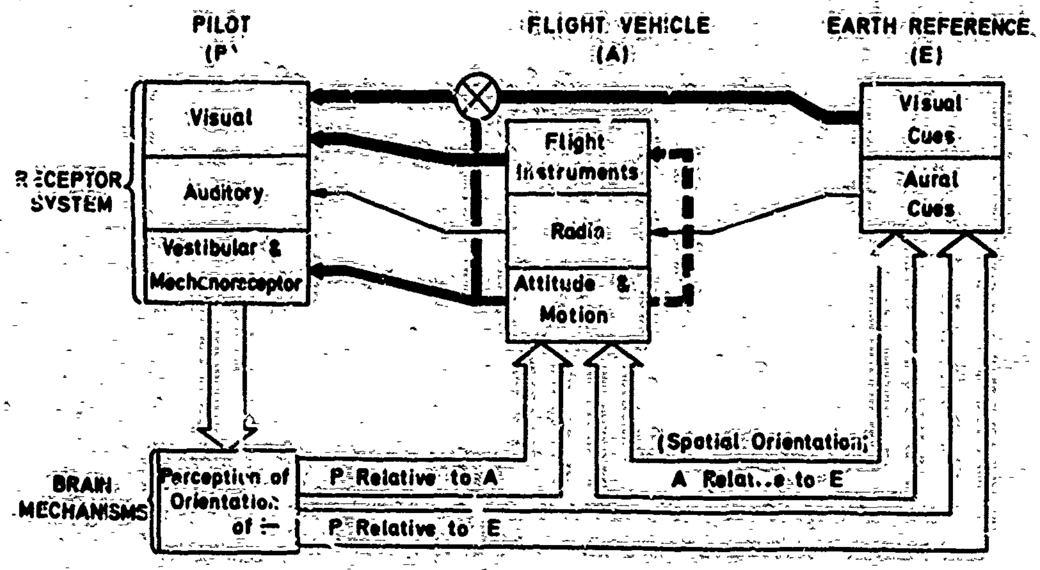

Fig.1 Diagrammatic representation of the sensory cues employed by the aviator to perceive his orientation with respect to his aircraft and to the earth, as well as the spatial orientation of the aircraft.

TABLE 1.

Pilot	Principal feature of illusory perception	Sensation Cupulogram Yaw	Roll
1	Banked and slow turn to left	L = R	L > R
2	Left wing low	R > L	L > R
3	Yaw and roll to left	L = R	L > R
4	Descending turn to right	L = R	R > L
5	Banked & turning, right or left	L = R	L = R
6	Wing low, right or left	L >> R	L > R
7	Banked and turn to left	L = R	R > L
	Proportion of asymmetry	2/7	6/7

Table 1. Nature of illusory sensations and results of cupulometric tests in 7 pilots with 'break-off' and qualitatively false perceptions of aircraft orientation.

isolation and an unchanging sensory input. Furthermore, alteration of awareness with derealization and depersonalization are features of several psychiatric disorders as well as toxic states and organic disease of the central nervous system.(6)

In an attempt to limit the breadth of clinical material to be studied, the present enquiry was confined to those aircrew who experienced symptoms characterised by an altered awareness of their orientation and relationship to the aircraft or the earth, when flying at high altitudes or in visual conditions of flight comparable to those experienced at high altitude. This selection procedure yielded 23 aircrew whose reports of the sensations experienced in flight had the cardinal features of the 'break-off' phenomenon. The mean age of the group, who were all pilots, was 33.6 yr (range 21-48 yr) and the mean flying experience was 2,892 hr (range 400-13,000 hr).

Although, by the nature of the selection procedure employed all the aircrew studied had experienced dissociative sensations, usually expressed as a feeling of detachment and remoteness from the aircraft they were piloting, in many there was an associated disturbance of perception of the attitude or motion of the aircraft. An example of 'break-off' uncomplicated by this particular type of spatial disorientation is provided by the case history of a 39 yr old Canberra pilot with 2,800 hr flying experience.

CASE HISTORY NO 1 'BREAK-OFF' WITHOUT FALSE PERCEPTION OF AIRCRAFT ORIENTATION.

This pilot presented with a two year history of episodic feelings of unreality and detachment when flying at high altitude. He had no symptoms until he had to carry out calibration flights in the Canberra (B2) which entailed flying at height of approximately 40,000 ft on a constant heading for a 30-60 min period. When the horizon was indistinct and the ground obscured by cloud or featureless, as when flying over the sea, he was on occasions overcome by a 'feeling of unreality' and remoteness from the aircraft. These sensations were accompanied by apprehension and a fear that he might lose consciousness and control of the aircraft. However, he was always able to maintain full control and there was no change in his appreciation of aircraft orientation. Anxiety was also manifest as muscular tension and sweating.

Symptoms commonly continued for as long as he had to fly straight and level on fixed heading and had been experienced for 90 min on occasions though 20 min was more typical. Symptoms disappeared as soon as a well defined external visual reference was available, or conversely when he flew into cloud and had to fly solely by instruments. Any distraction such as talking to his navigator or alteration of flight path could alleviate symptoms, though only when such an event occurred spontaneously. Volitional attempts by him to redirect his attention rarely modified his symptoms.

Over the two year period, he had experienced such perceptual disturbances on about 20 occasions. He sought medical advice because of increasing severity of symptoms in flight and the development of anticipatory tension a day or two before a flight in which he thought symptoms would occur.

In the remaining 20 aircrew there was some error in the perception of the attitude or motion of the aircraft. Most commonly this took the form of a feeling of instability described as 'like being balanced on a knife edge', or 'the aircraft is suspended in space on the point of a needle'. In all but one of the pilots this sensation was accompanied by apprehension, frequently expressed as a fear that 'the aircraft might fall out of the sky'. The principal features of this sub-group of patients is contained in the following history.

CASE HISTORY NO 2 'BREAK-OFF WITH INSTABILITY.

A 21 yr old Flying Officer first experienced symptoms during conversion training in the Canberra. During a daytime flight at 40,000 ft when required to fly straight and level for 5 min in hazy conditions with an indistinct horizon, he was suddenly overcome by a feeling of isolation and of being 'out of touch' with the aircraft. He found that he was gripping the controls tightly and beginning to sweat. He was aware that he was breathing heavily but not of paraesthesiae or any clouding of consciousness. In addition there was a feeling that he was on a 'razor's edge' and that the aircraft was about to 'fall out of the sky'. Symptoms persisted for the duration of the exercise at altitude (2 hr) and disappeared only when he began to descend.

In the four months following the initial incident he experienced similar symptoms on about 10 occasions. These occurred when flying straight and level at altitudes in excess of 30,000 ft. Coupled with the feeling of instability was the fear that he might become disorientated if he were required to fly on instruments and he was anxious about his ability to deal with an emergency should one occur. Yet on no occasion was his control of the aircraft degraded nor did his navigator notice anything untoward.

This apprehension about the recurrence of incidents in flight progressively increased. He vomited before take-off on two occasions and he began to sleep poorly. He became very anxious and tense on a climb through cloud to 30,000 ft; the canopy was iced up and the horizon hazy. Severe symptoms lasted for 30 min until a clear horizon was visible. On landing he reported to his Squadron Commander and asked to be suspended from flying.

Other aircrew described incidents in which the derealization symptoms of 'break-off' were coupled with more specific false perceptions of the orientation of the aircraft. These would appear to fall into two categories, one in which the perception of aircraft orientation was quantitatively false,

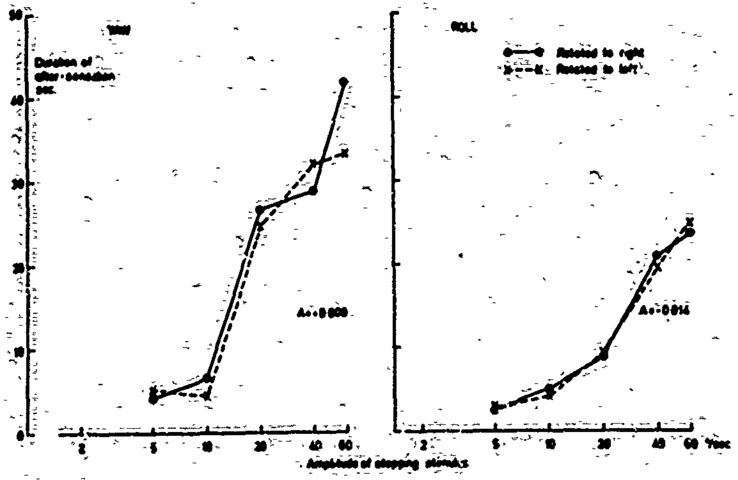

Fig.2A Sensation cupulograms for yaw and roll axis stimuli of a pilot who experiences 'Break-off' without illusory perception of aircraft orientation (Case history No.1).

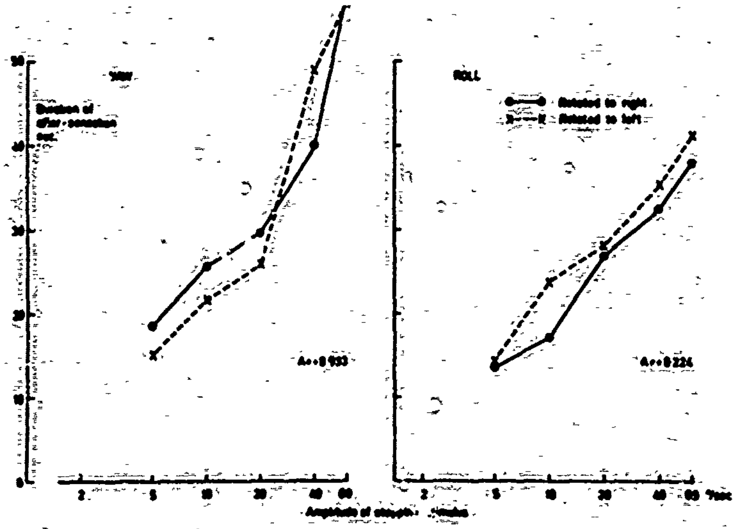

Fig.2B Sensation cupulograms in yaw and roll of a pilot who, in addition to the dissociative sensations of 'Break-off', felt that the aircraft was banked and turning to the left when flying straight and level. (Case history No.4).

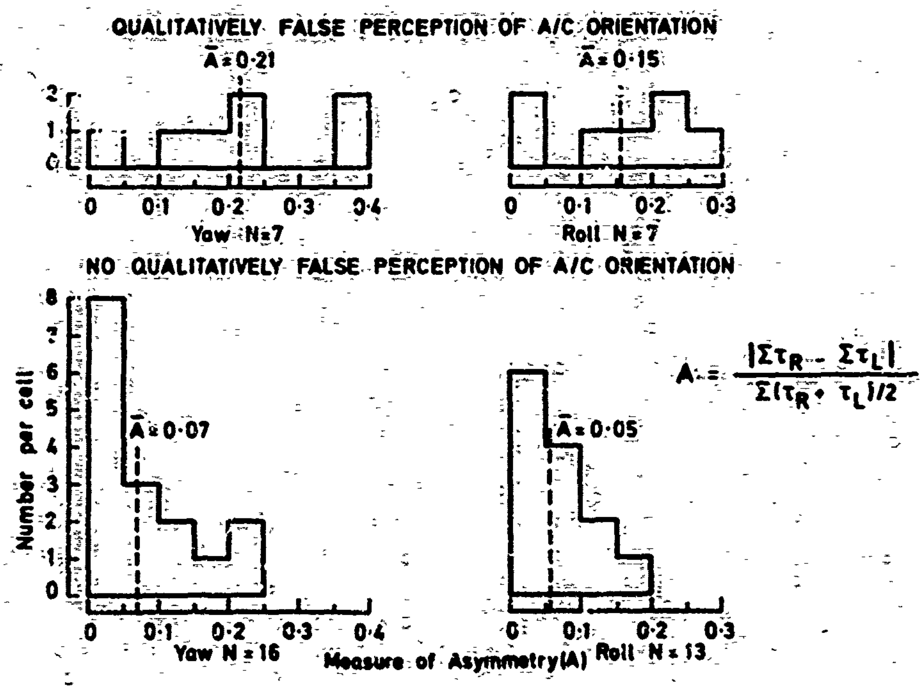

Fig.3 Distribution of a measure of asymmetry obtained from the sensation cupulograms of 7 pilots in whom 'Break-off' was accompanied by quantitatively false perception of aircraft orientation (upper half of the figure) and from 16 pilots who did not have associated 'spatial disorientation' (lower half). $\Sigma\tau_R$ and $\Sigma\tau_L$ represent the total duration of all after-sensations evoked on stopping turntable rotation to the right and to the left respectively.

and the other where it is qualitatively false. The former of these two categories would perhaps be better described as an exaggerated perception of the attitude or change in attitude of the aircraft. The latter represents an illusory perception in which the perceived orientation of the aircraft contains elements which are qualitatively different from the correct orientation. Most of the commonly recognised examples of spatial disorientation in flight fall within this category e.g. the 'leans', or false sensations of angular motion following recovery from prolonged rolling and spinning manoevres.

An example of 'break-off' associated with a quantitative error in the perception of aircraft motion is illustrated by the incident reported by another Canberra pilot.

CASE HISTORY NO 3: 'BREAK-OFF' WITH QUANTITATIVE DISORIENTATION.

Over a five month period a 28 yr old pilot with 1,500 hr flying experience had felt somewhat 'uneasy' when flying at altitude at night. However, he was not unduly disturbed until one night, when flying at an altitude in excess of 40,000 ft in a PR7 Canberra, he had a feeling of being 'out of touch' with the aircraft. This sensation of detachment was accompanied by one described as 'dizziness' but on enquiring this was not a true vertigo (i.e. angular motion) but rather an exaggerated perception of the motion of the aircraft. He had difficulty in equating his sensations with the aircraft instruments and began to doubt his ability to control the aircraft.

Symptoms disappeared during descent but he was acutely disturbed by the incident which was accordingly reported to his Station Medical Officer.

Amongst the sensory disturbances associated with 'break-off', as first described by Clark & Graybiel (5), no mention was made of false perception of aircraft orientation, and in a later paper by Sours (7) it was specifically stated that none of the aviators with 'break-off' had 'spatial disorientation'. However, in the present series it was found that seven pilots experienced an illusory perception of aircraft orientation in which there was a qualitative error in the perceived attitude or motion of the aircraft, i.e. there was 'spatial disorientation' if this term is used in the commonly accepted sense.

Typically the false sensation of aircraft orientation occurred when the pilot had levelled out at cruise altitude and had entered a relatively monotonous phase of t flight. The case history of a 25 yr old pilot with 510 hr flying experience illustrates the principal features of this group of patients.

CASE HISTORY NO 4: 'BREAK-OFF WITH QUALITATIVE DISORIENTATION.

This pilot . essfully completed initial and conversion training but shortly after joining a (rra (B.15) squadron he began to be troubled by 'disorientation' when flying at night. Characteristically, symptoms did not occur until 10-15 min after he had levelled out at cruise altitude, usually at a height in excess of 30,000 ft. He would then begin to feel out of touch with the aircraft and uneasy. Concomitantly, there was a sensation that the aircraft was banked 30-40° left wing low which at times was associated with a false perception of a slow turn to the left. Although the instruments indicated level flight, he had difficulty in resolving the conflict. He made small corrections (5-10°) in roll attitude which interfered with the maintenance of an accurate heading, while accuracy was further degrad d by coarse movements of the control column which he gripped with increased force. The perceptual and motor disturbances made him apprehensive and he began to doubt his ability to maintain control. These symptoms persisted all the time he was on instruments and disappeared only when the lights of a city or runway were clearly visible.

Over an 18 month period he had similar incidents whenever he flew at night. Although the perceptual disturbance did not change noticeably, he became more apprehensive and less confident of his ability to fly safely. He was suspended from flying and sent for medical assessment because of an aborted night take-off in which he became confused and distracted by the runway lights.

It was found that all 7 pilots with qualitatively false perception of aircraft orientation felt that the aircraft was banked or turning when ir ight and level flight. Such illusions are of a type most commonly experienced by aviators (C). T ordered perception associated with 'Break-off' did not appear to engender illusory sensations of a raft orientation which differed in any distinctive manner from those experienced by aviators without dissociative sensations.

A more detailed comparison is made later of the 7 pilots with 'break-off' and qualitatively false perceptions of aircraft orientation with the 16 pilots in whom 'break-off' was not associated with 'spatial disorientation'. In other respects these two groups were very similar. The mean age and flying experience of the 7 pilots with 'spatial disorientation' was 33.5 (S.D. 7.19) yr and 3455 (range 510 - 13,000) hr respectively; comparable figures for the 16 pilots without disorientation were 33.6 (S.D. 7.11) yr and 2736 (range 300 - 6,000) hr.

'Break-off' in helicopter pilots

The case histories so far presented were all provided by pilots of fixed wing aircraft. However, we have seen four helicopter pilots who reported derealization symptoms comparable to those experienced by pilots of conventional aircraft; the principal difference between fixed and rotary wing pil is that the latter had 'break-off' during flight at altitudes of less th 10,000 ft.

wo helicopter pilots experienced symptoms during long straight . over the sea to off-shore drilling rigs. The experience of a 48 yr civilian he pter pilot described overleaf, is in many respects typical.

CASE HISTORY NO 5 HELICOPTER PILOT WITH BREAK-OFF

A helicopter pilot with over 3,000 hr flying experience frequently made service flights to off-shore drilling rigs in the Persian Gulf. On one such flight similar to those which he had made many times before during the preceding 3 years, he had climbed to 500 ft and set course for the off-shore rig; the horizon was poorly defined because of haze and the sea below was calm and nearly featureless. After flying for about 10 min at constant heading and altitude, he suddenly experienced a 'light-headed feeling', and that he was 'out of touch' with his immediate environment. He became more aware than usual of small movements of the helicopter, but there was no qualitatively false perception of its orientation. No other symptoms characteristic of hyperventilation were experienced, though he became tense and tended to overcontrol. The derealization and other symptoms persisted until he saw the off-shore rig and began to descend. Because of this unusual sensory experience he returned to the mainland with a co-pilot and had no symptoms.

He had no further trouble for 5 months when, in circumstances essentially identical to the first incident, he again had feelings of unreality. On this occasion he became more apprehensive and felt that he would be unable to cope with an emergency should one arise. Symptoms disappeared on landing, though he still felt somewhat ill at ease. During the subsequent 2 days he made 5 flights, each more disturbing than the preceding one. By this time he was agitated and seriously doubted his ability to fly with safety, so he reported the incidents to his Medical Officer.

The other very experienced pilot also developed a feeling of insecurity during flight over a featureless sea at a height of 800 ft with a clear sky and hazy horizon. He was so alarmed by the sensation that the helicopter was 'balanced on a knife edge and felt as if it might topple out of the sky' that he reported the isolated incident to his medical officer. An explanation of the underlying cause of the altered perception probably prevented the development of a vicious circle with increasing anxiety, so clearly demonstrated by case history No 5.

The role of visual cues of orientation in the genesis of derealization symptoms is illustrated by the history of a Squadron Leader.

CASE HISTORY NO 6 BREAK-OFF IN HELICOPTER PILOT WITH PRESBYOPIA

A 45 yr old officer with over 5,000 hr experience had flown light helicopters (Sycamores) for 10 years without incident. However, during conversion training in the Wessex helicopter he experienced perceptual disturbance when flying at night. Typically, the take-off and ascent to 500 ft on instruments was without incident, but on looking at the ground and then at the flight instruments these appeared blurred and he began to feel uncertain about the orientation of the helicopter and of himself with respect to the machine. He felt as if he was 'sitting on something that does not belong to me' and that the helicopter was 'balanced over a knife edge from which it might topple off'. He became more aware of the motion and noise of the aircraft, but there was no qualitatively false perception of its orientation. He gripped the controls and movements were made more precipitously so that he tended to overcorrect. In order to allay these disturbing sensations he would descend as close to the ground as possible in order to derive adequate visual cues of motion and attitude, but uncertainty and apprehension persisted until he landed.

Similar symptoms occurred on five sorties at night and also on several daytime flights in which he had to mix contact and instrument flying because of poor visibility. On all these occasions he experienced difficulty in seeing the instruments clearly on transferring his gaze from outside to inside the helicopter.

On examination he was found to be suffering from presbyopia and half spectacles were prescribed. He resumed conversion training and was free of symptoms when reviewed a year later.

In contrast, the 4th helicopter pilot was relatively inexperienced (475 hr, 315 hr on helicopters) and first experienced feelings of unreality and detachment during a flight at night at 700 ft in hazy conditions. 5 months later he was more seriously disturbed by similar symptoms on beginning to descend from level flight at 3,500 ft, again at night with industrial haze at the flight level. Despite reassurance, three further incidents occurred each with increasing anxiety and loss of confidence before he was grounded.

Relationship between illusory perception of aircraft orientation and vestibular function. As a contribution to the clinical evaluation of aircrew presenting with symptoms of 'disorientation' in flight, special tests of semi-circular canal function were carried out on all patients referred to the Royal Air Force Institute of Aviation Medicine. None of the patients in the series here reported were considered to have organic disease. This opinion was based on the findings of a routine neuro-otological examination, which included the Fitzgerald & Hallpike (9) Caloric Test, when the normality of vestibular function was in question.

Because disorientation is a perceptual disturbance, the tests of vestibular function carried out were primarily concerned with the sensations evoked by adequate stimulation of the vestibular receptors. The test procedure employed was that of sensation cupulometry (10) the technique employed following closely that of Aschan et al. (11). The subject sat or lay with eyes closed on a turntable which was accelerated at $1^{\circ}/sec^2$ to a velocity of $60^{\circ}/sec$. After 60 sec at constant speed the turntable was stopped by a mechanical brake and the subject asked to press a key when the sensation of turning

disappeared. Following the first angular stimulus the test was repeated, but with the table rotating in the opposite direction. Subsequent stopping stimuli were administered with rotational speeds of 40°/sec, 20°/sec, and 5°/sec. The direction of rotation was alternated between each test stimulus. Finally the 60°/sec stimuli were repeated. Post-rotational lateral nystagmus was also recorded by means of a conventional electro-oculographic technique.

The initial test procedure was first carried out with the subject seated on the turntable with the head supported in a vertical position. In this position the angular stimulus acts in the z axis of the skull and is equivalent to yawing motion in flight. The duration of after-sensations were also determined when the subjects lay in the supine position on the turntable. This configuration allowed the sensitivity of the sensory system to roll axis stimuli to be assessed.

The duration of the after-sensations were plotted against the logarithm of the intensity of the step velocity stimulus, in the conventional form of a sensation cupulogram (Fig 2). From a straight line drawn through the points, measures of the time constant of the exponential decay of the after-sensations and of sensory threshold were obtained, both for the yaw and roll axis stimuli. Comparison of these values, for the 7 aircrew with qualitatively false perception of aircraft orientation with the 16 who did not experience such illusory sensations, failed to show a significant difference in any of the measures. Likewise there was no significant difference in these measures of vestibular sensitivity between the 5 aircrew who experienced a heightened awareness of aircraft motion and those who did not report this symptom.

Analysis of measures of the post-rotational nystagmus also failed to demonstrate any significant difference between the group of pilots with 'spatial disorientation' and the group in whom 'break-off' was not accompanied by such false perceptions. The measures studied were all obtained from plots of nystagmus slow phase velocity for the first 30 sec after stopping and included: the peak slow phase velocity, the time constant of decay and measures of directional preponderance derived from these two variables.

Although the measures of 'slope' and 'threshold' of the sensation cupulogram did not appear to differentiate the group of pilots with 'spatial disorientation' from the group without this perceptual disturbance, measures of the difference between the duration of the after-sensations, for angular stimuli to the right and to the left, were found to be of greater value. An individual cupulogram was considered to show directional preponderance if the durations of the after-sensations produced by stimuli in one direction were consistently longer, or shorter, than for the stimuli of equal magnitude in the opposite direction. Thus in Fig.2 the roll axis cupulogram of the pilot with 'spatial disorientation' (case history 4) was regarded as asymmetrical, as all the after-sensations following rotation to the left were longer than the after-sensations produced by the same intensity stimuli to the right. The other 3 cupulograms illustrated were not considered to demonstrate directional preponderance, because the difference between the after-sensations to the right and to the left was not consistent over the 5 turntable speeds employed. When this criterion was applied to the individual yaw and roll axis cupulograms it was found that an appreciably larger proportion of the aircrew with qualitatively false perception of aircraft orientation exhibited directional preponderance than the other 16 without this type of disorientation. Furthermore, in at least 4 of the 7 pilots the asymmetry was in agreement with the false perception of aircraft orientation experienced in flight.

As a specific example, consider the roll axis cupulogram of Fig.2B obtained from a pilot who, when flying straight and level at high altitude felt that the aircraft was banked and turning slowly to the left (case history No.4). The sensation cupulogram for roll axis stimuli shows consistently longer after-sensations following rotation to the left than to the right. Now for a subject lying in the supine position on a turntable, rotation to the right (i.e. in a clockwise direction when viewed from above) is equivalent (as far as angular motion is concerned) to rolling left wing low in an aircraft, and on stopping the evoked sensation is equivalent to rolling right wing low. Thus a cupulogram of the form shown in Fig.2 implies a greater sensitivity to roll-left wing low than roll-right wing low.

Now it is suggested that in flight, if the pilot's awareness of vestibular sensation is heightened, then relatively minor degrees of vestibular asymmetry can be the cause of disorientating sensations.[12] Thus an asymmetry in roll, say to the left, may be perceived as angular motion of the pilot to the left; a perception which is extended to embrace aircraft motion of roll to the left because of the close perceptual linkage between pilot and aircraft. Although the signals from the semi-circular canals primarily carry information about the velocity of angular motion these signals can be integrated within the central nervous system to give an accurate perception of the change in angular position.[13] The illusion engendered by an asymmetrical canal response may thus be manifest as a false sensation of either angular velocity or angular position.

The illusory perception of aircraft orientation experienced by the pilot, whose cupulograms are shown in Fig.2B was that the aircraft was banked and turning to the left. This illusion accords with the laboratory demonstration of a roll axis asymmetry in the sensation cupulogram where there was greater sensitivity to angular motion in the left wing low than in the right wing low direction. The demonstration in one pilot of a vestibular asymmetry which could account for the illusion experienced in flight does not establish a causal relationship. However, in the 6 other pilots with false perception of aircraft orientation, vestibular asymmetry was demonstrated in all but one. Table 1 summarises the findings in the 7 pilots. It may be seen that an asymmetry compatible with the in-flight illusion was present in at least 4 pilots. Of the other 3, 1 pilot could not remember the direction of the illusory perception of bank and turn, and another had no directional specificity. Only in 1 pilot was there a directional preponderance of the sensation cupulogram which did not accord with the false perception of aircraft orientation (Pilot 7).

In contrast to the finding of minor degrees of vestibular asymmetry in 6 out of the 7 pilots with qualitatively false perceptions of aircraft orientation, only 2 aircrew out of the 16 without 'spatial disorientation' were found to have asymmetric responses. The difference between the 2 groups of patients is better illustrated by Fig.3 which shows the distribution of a measure of asymmetry obtained

from the after-sensation durations. The measure employed, which makes no assumption about end organ dynamics, represents the modulus difference of the summed durations of the after-sensations to the right at all 5 stimulus intensities from the summed durations of the after-sensations to the left. In order to minimize inter-subject variation, the difference in the after-sensations attributable to the direction of rotation is expressed for each subject as a proportion of the total after-sensation time, obtained by averaging all right and left after-sensations. Statistical analysis of the asymmetry measures demonstrated that the group of pilots with qualitatively false perception of aircraft orientation had significantly ($P = 0.01 - 0.05$) greater asymmetry in both the yaw and roll axes than did the group of aircrew who experienced comparable symptoms of derealization but without 'spatial disorientation'. Likewise, the distribution of the asymmetry measure was also found to differ significantly ($P = 0.02 - 0.05$) between the two groups, in both the yaw and the roll axis. Although the number of observations is small and does not permit the shape of the distribution curve to be determined with accuracy the findings suggest that in the group without 'spatial disorientation' the asymmetry measure was normally distributed, whereas in the group with 'spatial disorientation' there was a bimodal distribution of the measure. These inferences apply to the measure of asymmetry with attention given to the sign of the response and not to the modal values depicted in Fig.3.

DISCUSSION

In this paper an attempt has been made to examine the dissociative symptoms characteristic of the 'Break-off' phenomenon, as a feature of the broader problem of disordered perception of orientation in the flight environment. The picture which emerges is that the derealization of 'break-off' may be coupled with a variety of illusory perceptions of aircraft orientation. In its least structured and most common form this illusory perception is presented as a feeling of instability, though less frequently there is a heightened awareness of aircraft motion with an exaggerated perception of the attitude or change of attitude of the aircraft. In about a third of the aircrew examined, illusory perception of attitude and motion occurred when the aircraft was flying straight and level, and represent the type of illusion which is conventionally described as 'spatial disorientation'.

It is of interest that in the studies of 'break-off' made by Clark & Graybiel (5) and Sours(7) in the USA and by Lomonaco (14) in Italy, illusory perception of aircraft orientation was not associated with derealization symptoms in any of the aircrew interviewed. Yet in two out of the five cases presented by Bennett (15) pilots felt as if the aircraft was banked or turning. This difference in incidence can probably be attributed to the selection procedures employed in the various studies. The authors who found no associated 'spatial disorientation' interviewed a relatively unselected aircrew population, whereas in the present study, as with that of Bennett (15), the symptoms experienced in flight had led the aircrew to seek medical advice.

From the surveys carried out it is apparent that dissociative sensations are not infrequently experienced by aircrew during monotonous phases of flight at high altitude, the incidence ranging from 13.5% (ref. 14) to 35% in Clark & Graybiel's (15) series. Sours (7) also found that 35% (6 out of 17) of aircrew who were referred for neuro-psychiatric assessment and had flown at high altitudes, had personal experience of the 'break-off' phenomenon. The majority of 'normal' aircrew report that 'break-off' is characterised by a feeling of elation, exhilaration and excitement, but in about a third (38%, ref.5) instead of pleasurable sensations, derealization was accompanied by apprehension and anxiety. In contrast, only one of the pilots examined by Sours (7) found 'break-off' to be entirely pleasurable, while in the present series the sensory disturbance was, without exception, associated with feelings of unease and apprehension. This finding illustrates the point made earlier, namely that the pilots described in this report were, like those studied by Sours (7) not representative of the normal aircrew population, but were drawn from that third in whom 'break-off' was a disturbing rather than a pleasurable experience. Indeed, in all of the 23 pilots studied, the perceptual disturbance was associated with manifest anxiety. Such anxiety reactions were, in the majority of aircrew, confined to the flight environment and in 10 individuals were sufficiently specific and repetitious to be labelled phobic anxiety. Significant generalisation of the anxiety reaction had occurred in only 3 pilots. Thus it would appear that the 'Break-off phenomenon' was, in most cases, the precipitant of a neurotic reaction, for other factors which could be regarded as being of prime aetiological significance were only apparent in 3 pilots. In this respect our findings are in agreement with those of Sours (7) who considered that 'break-off' could be the precipitant of an anxiety reaction in susceptible individuals.

The association of derealization and depersonalization with phobic anxiety raises a more difficult nosological problem. In the majority of cases seen, the perceptual disturbance was clearly the precipitant of the phobic anxiety which, once established, potentiated the dissociative symptoms in the manner of a conditioned response. On the other hand, there were 2 patients in whom such a causality was not so apparent and the diagnosis of a phobic anxiety - depersonalization neurosis (16) could be entertained if not firmly established.

Apart from anxiety reactions, dissociative sensations also feature in many other clinical entities known to psychiatry, and can be produced by organic lesions and toxic states. In the group of aircrew studied, only hyperventilation appears as an aetiological factor of importance. This condition was revealed without ambiguity in the anamnesis of one pilot, where the hyperventilation was apparently secondary to the apprehension engendered by the perceptual disturbance.

The conditions of the flight environment which engender 'break-off' have been likened to those of sensory deprivation (6, 7, 15, 17) where initially the lack of change in the sensory environment - the restricted sensory input - brings about an alteration of the behavioural state. Thus, pilots when flying straight and level at a constant heading, with little structure and no apparent change in the external visual environment are, (to use Hebb's (18), concept of an 'arousal continuum') likely to pass from a normal level of arousal into a behavioural state in which the level of arousal is low. Although such low arousal conditions may be the milieu in which 'break-off' occurs, it is apparent that the sensory experience of 'break-off' is associated more with a high than a low level of arousal. Certainly high arousal is a normal concomitant of anxiety, but even in the majority of aircrew where there was no apparent anxiety there was

a feeling of elation and exhilaration [5] which was more in accord with a behavioural state where the level of arousal was high than one in which it was low. It would appear likely that dissociative symptoms which occur in 'break-off' can be both a manifestation of a high level arousal and also, as a result of the individual's awareness of an alteration in subjective state, the cause of heightened arousal. But the mechanism by which the altered sensory environment brings about the perceptual disturbance remains obscure.

There would appear to be two principal factors necessary for the induction of 'break-off'. One is the paucity of orientational cues in the pilots external visual environment and the other is a relatively constant flight path. Altitude per se cannot be regarded as a prime aetiological factor, for Eastwood & Berry [19] have reported that 'feelings of detachment from one's surroundings' were experienced by 'many' helicopter pilots when flying at altitudes of 5,000 - 8,000 ft. Furthermore the case histories of helicopter pilots presented in this paper clearly indicate that comparable dissociative sensations can occur at altitudes of only 500 ft, providing external visual cues are sufficiently attenuated. There would seem to be an inter-relationship between altitude and aircraft type, for in fixed wing aircraft 'break-off' rarely occurs below 20,000 ft and commonly an altitude in excess of 30,000 ft is required for induction of symptoms. The differences may be due to the lower air speed of helicopters, or the more extensive view from the cockpit without substantial air frame reference. Or is it that control of the helicopter, because it is an inherently unstable vehicle, is a more demanding task than piloting a fixed wing aircraft at constant height and heading?

Perhaps the fundamental cause of 'break-off' lies not so much with control of the flight vehicle, but in the pilot's appreciation and awareness of his situation in a device which supports him, as it were unnaturally, many thousands of feet above the surface of the earth. As part of this cognitive process, released by the relative constancy of the sensory environment, consideration of the stability of the flight vehicle and the performance envelope in which the pilot has to operate could well play a significant role. The uncertainty generated by such free ranging thought processes would appear to be resolved by visual cues of 'spatial orientation.' But if these are inadequate, the uncertainty is not resolved, the level of arousal increases and the dissociative sensations of 'break-off' may be engendered.

CONCLUSION

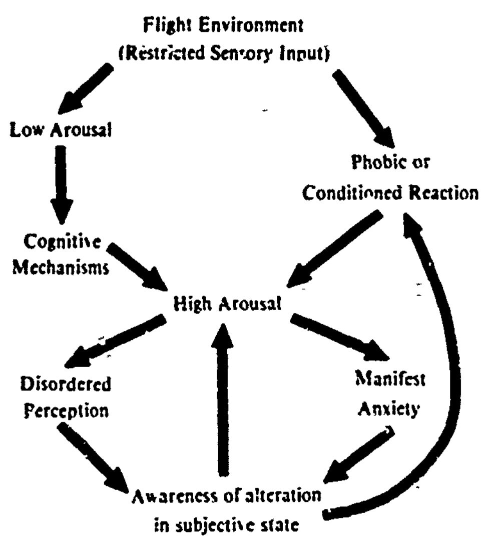

Fig.4 Conceptual scheme showing the inter-relationship of the flight environment to 'Break-off' and anxiety.

Although the precise mechanism underlying the perceptual disturbances of the 'break-off' phenomenon is inadequately understood, certain features and functional relationships are established and are summarized in diagrammatic form by Fig.4. This conceptual scheme is, without doubt, an oversimplification, but it serves to emphasise the inter-relationship between 'break-off', arousal and anxiety. The presence of a closed loop, a vicious circle mechanism, in which the individual's awareness of the dissociative sensations heightens arousal, illustrates the role of 'break-off' as the focal point of phobic anxiety or the precipitant of anxiety reactions. Knowledge of such aetiological mechanisms may be of value to the medical officer in the diagnosis and treatment of aircrew with fear of flying or other neurotic reactions. Yet it is of greater importance to recognise that neurosis and wastage of highly trained personnel may be prevented by instructing aircrew about the perceptual disturbances which can occur in the flight environment. Today, nearly all aircrew are familiar with the common illusions of aircraft orientation, but knowledge about the sensory disturbances characteristic of the 'break-off'phenomenon is less widespread. The dissociative sensations of 'break-off' even when associated with false perceptions of aircraft orientation, do not appear to present a serious threat to the safety of flying personnel. Nevertheless there is a penalty, for the perceptual disturbance can be distracting and the pilot's attention may be diverted from more important aspects of the flying task. Performance may also be degraded by anxiety, particularly when this is manifest as muscular tension or hyperventilation. However, from the aeromedical viewpoint, the principal feature of the 'break-off' phenomenon, is that it may be either the precipitant or the manifestation of an anxiety neurosis.

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DISCUSSION

WOODWARD. Would you comment on the apparent discrepancy between (i) disorientation such as 'break-off' resulting from reduced information, and (ii) disorientation or 'vertigo' resulting from overload of information. Are they equivalent?

BENSON. The distinction which I attempted to make at the beginning of my paper was between disorientation in which there was an erroneous perception of the orientation of self (ie the pilot) in relation to the aircraft and earth reference, and disorientation in which the erroneous perception was of aircraft orientation. In discussing pilot disorientation, or aviators' vertigo as it is commonly called in the US, we commonly refer to those incidents in which the perception of aircraft orientation was wrong - this after all is the most important thing when talking about loss of control and aircraft accidents due to disorientation.

The disordered perception of orientation of pilot relative to the aircraft, which is a common feature of the dissociative sensations characterised by the 'break-off phenomenon', may be no less disturbing to the aviator, though it rarely interferes with aircraft control other than by the anxiety engendered in some individuals.

Equivalence between these two types of disorientation would appear to rely only on the fact that they are both perceptual disturbances of spatial relationships. It is all a matter of how one defines spatial disorientation in flight.

PERRY. I would just like to remark on the fact that dissociative sensations have been in the past a fairly frequent occurrence in trainee helicopter pilots, especially in the types of helicopter where there is a large open visual area in front of him. We accepted the phenomena as something which was likely to occur during flying training and hence should be explained to the student as well as giving him some way of curing it, when it happened.

The commonest description was one of sitting on top of the canopy (outside the aircraft). This was very frightening, even when only for a fleeting moment. We endeavoured to cure the fear, by suggesting that when finding oneself in this state, remember you are not really there, there is no 100 kt air flow, your head has not been struck by the main rotor, but above all, you still have the controls in your hands, so you can fly the machine no matter where you feel you are.

This basic knowledge, given to the students in their first few days, has reduced the number of reported incidents, probably by removing their anxiety about the situation.

BENSON. Thank you for that interesting observation. It is however surprising that 'break-off' like symptoms in helicopter pilots is mentioned only in one published paper (as far as I know). Yet from your own experience, the paper of Dr Clark (A1), and from the six cases I have seen it is as common, if not more so, in helicopter pilots as in pilots of fixed wing aircraft. The occurrence of 'break-off' at lower altitudes in helicopters than conventional aircraft implies to me that the 'constancy of the sensory environment' which is regarded as a prime aetiological factor in this condition, is of less importance than the aviator's concept of the 'stability' of the vehicle he is flying. I have discussed aetiological mechanisms in my paper, though I admit that these are hypothetical. Perhaps some member of the audience can provide a better explanation of the mechanism the 'break-off' phenomenon.

VIOLETTE. The 'break-off phenomenon' can be a pleasurable experience, but 'outside the body' sensations can also be unpleasant and accompanied by a state of anxiety and instability. This phenomenon is generally observed in subjects with a tendency to anxiety with problems of either a sentimental, social or career nature. I believe that they feel 'uncomfortable in the skin' which they are 'trying to leave'.

I have also seen a type of 'break-off' in students who are making a great mental effort for examinations. These students were not under the influence of any drug, but engaged in a rhythm of intellectual work for 14-16 hr per day. They have reported a feeling that they were leaving their body and floating in space outside themselves. This sort of hallucination is dispelled very effectively by mild tranquilizers such as Mandrax.

BENSON. Thank you for these observations which serve to underline the fact, that the dissociative sensations, which are a cardinal feature of the 'break-off phenomenon', also occur in a number of psychiatric conditions and intoxications. Yet it must be recognised that the unusual sensations of 'break-off' do occur in aviators whose mental health is not in question, although in others these symptoms may be the manifestation of a neurotic reaction. It must also be recognised that in susceptible individuals dissociative sensations can precipitate an anxiety neurosis.

VERTIGO IN DIVERS*

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SUMMARY

Documenting the surprising frequency of the occurrence of vertigo in hyperbaric atmospheres and in divers, the author presents a summary of his review of the literature and the theories that have been advanced to explain the etiology of vertigo under these circumstances. These include barotrauma, damage from the formation of bubbles, hyperemia and hemorrhage, unusual displacement of the stapes, caloric stimulation, slow movement of ear drum and ossicles causing eddy currents, performance of the valsalva maneuver, or the sudden clearing of a blockage in one ear, and disturbed labrynthian function. The author feels that vertigo is a grave menace occurring with a high degree of frequency among divers, and that this condition has not been given adequate consideration and study. It warrants wider recognition and continued research by workers in the field of diving medicine.

INTRODUCTION

Vertigo is surprisingly frequent in diving. Reviewing the existing literature relative to this symptom complex, we must arrive at the conclusion that vertigo, which can be life-endangering to a diver, has been viewed with a degree of complacency in diving medicine. With the increasing interest in underwater work in the Navy, industrial underwater exploration, as well as the prolific SCUBA diving activities as a business and as sport, we are led to believe that vertigo as a risk in diving should be more closely investigated.

REVIEW OF THE LITERATURE

Vertigo in caisson workers has been a recognized complication for many years. In 1896, Alt[1] reviewed three cases of labyrinthitis and nine cases with Meniere-like symptoms in caisson workers. In his discussion, the associated vertigo was attributed to barotrauma. This is a generalization that establishes the scope of the problem, but is hardly definitive in pinpointing the specific etiological factor.

In 1896, Friedrich and Tauzk[2] reported a case of a caisson worker with vertigo lasting for 14 days. From 1900 to 1907, Tomka[3], Heermann[4], and Philip[5,6] all reported cases of caisson workers that involved vertigo or Meniere-like symptoms. In these cases, the symptoms, including the vertigo, were believed to be due to ischemic lesions in the labrynthe. This etiological factor was especially espoused by Heermann.

In 1909, Keays[7] reported on 3690 cases of caisson disease in which he reported 113 with symptoms of vertigo and 14 with the classic Meniere's syndrome. His interpretation as to the etiology again was a non-specific barotrauma. Thost[8] in 1921 described dizziness and disturbances of equilibrium in some caisson worker patients also quoting evidence of gas bubbles in the mastoid process. In 1929, Thost[9] also discussed effects on the middle and inner ear in caisson workers. He lists three etiological factors for pathology in these areas; one being the effect of pressure on the vestibular apparatus which may terminate in vertigo, among other symptoms.

In 1929, Vail[10] reporting on caisson disease with vertigo, concluded that the vertigo was caused by damage to the cochlea and vestibule by the formation of intravascular bubbles. Fields[11] in treating four cases of labyrinthitis with vertigo in divers, postulated in 1958 but the vertigo was due to an unusual displacement of the stapes in the oval window giving temporary symptoms of vertigo. Rowe[12] in the Australian Medical Journal in 1961, postulates that caloric stimulation is the most important mechanism in the production of vertigo in divers.

*Paper presented by Commander J.D.Bloom, MC, USN.

Melvill Jones[13] postulated a vertigo-producing mechanism in fliers in 1957. He stated that rapid changes in altitude with inability to readily equalize middle ear pressure caused slow movements of the ear drum and the ossicles. He believes that these slow movements produce eddy currents in the endolymph over the utricular and saccular maculae and the ampullar cupolae which probably cause the vertigo syndrome. Lundgren[14] in the British Medical Journal in 1965, reported on data accumulated on 354 members of the Swedish Association of Sport Divers. 92 members, or 26%, reported that they had experienced true vertigo during SCUBA and free diving. The largest number, 73, experienced their vertigo while SCUBA diving.

Of the total number of divers who experienced vertigo, 95% experienced it occasionally, while 5% experienced it in every dive. The vertigo episodes described by Lundgren in the subjects who answered his questionnaire, ranged from not troublesome to very troublesome. Since the very troublesome group comprised 18%, and included such statements as the vertigo causing an inability to orient themselves in the water, difficulty in swimming, nausea and vomiting, it appears that vertigo can be considered a dangerous affliction in diving.

Lundgren, in his discussion, points out that vertigo can be produced by applying the valsalva maneuver underwater in an attempt to clear the ears. He also states that vertigo may be produced by a pressure imbalance when one ear is blocked and is suddenly cleared. Lundgren postulates that the disturbed labyrinthine function during diving is caused by differences in pressure in the middle ear cavity and the surrounding structures. As most of his subjects had vertigo in the ascent or on reaching the surface, he thinks that relative overpressure in the middle ear is a primary factor.

He observes that asymmetry in pressure fluctuations in the two ears must also be a contributing factor. 30% of his divers who reported vertigo stated that they usually had difficulties in pressure equilibration. The theory of eddy current production in the endolymph, as espoused by Melvill Jones in his study in vertigo in aviators, undoubtedly is applicable to the diver's situation. Lundgren states that if the intensity and magnitude of the stimulus is a factor in the frequency of vertigo, it would be much more frequent in divers than in aviators. He suggests the term of alternobaric vertigo as a useful name for the syndrome.

Terry and Dennison[15] at the US Naval Submarine Medical School, New London, Connecticut published a study in 1966 on vertigo in divers who were attached to the Submarine Base Training Tank. Terry and Dennison's findings differ somewhat from those of Lundgren.

	Navy	*Lundgren*
Number of Subjects	37	354
Divers experiencing vertigo	40.5%	26%
Association with clearing one ear	20%	30%
Association with pressure changes	40%	27%
Water temperature involvement	40%	0%

Terry and Dennison conclude that vertigo is n occ nal symptom among divers and that it has not been given due consideration as a complicating factor. hey fe that the incidence of this symptom among divers is consonant with the experience of the diver; although if a man dives long enough, he will experience vertigo. Vertigo, when it manifests itself by loss of balance, nausea and unconsciousness, must be differentiated from the severe forms of dysbarism. Pressure changes within the middle ear and caloric stimulation may play an important role in its cause. Inequality of the caloric stimulation between right and left ears appea to play only a minor role. The important factor seems to be the movement of endolymph, whether by movements of the stapes causing eddy currents, or convection caused by caloric stimulation. The high incidence of vertigo among divers is worthy of further study.

In 1970, Vorosmarti[16] and Bradley reported on the results of a questionnaire evaluation of 143 US Navy divers relative to the occurrence of vertigo while diving. Eliminating all the ancillary factors that may cause vertigo, the authors reported that 11.9% of these men indicated that they had experienced vertigo in diving. The authors state that most of the reported incidents were of short duration and not troublesome.

As an exercise for this discussion, the writer reviewed 43 case histories of Navy divers requiring decompression treatment. These histories were loaned to him by Dr H.W.Gillen of the Indiana State Medical Center. The following data were extracted:

No. of cases	43	All Navy
No. Experiencing Vertigo	23	
Dizziness (true horizontal rotational vertigo)	23	
Blurring of vision and ocular disturbances	20	
Nystagmus	2	
Nausea	20	

Tinnitus	10
Incoordination	10
Convulsions	1

Most of these symptoms occurred in the ascent from a dive and were most pronounced on surfacing, thus requiring recompression. Three cases occurred on descent and at the bottom of the dive. In general, these findings relate to the data acquired by Lundgren, Terry and Dennison, Vorosmarti and Bradley.

DISCUSSION

In recapitulation, then, the several mechanisms of vertigo production in caisson workers and divers as postulated by various authors since 1896 are:

(a) General references to barotrauma.

(b) Ischemic lesions in the labrynthe.

(c) Hyperemia and hemorrhage of the labyrinth.

(d) Formation of intravascular bubbles in the internal ear.

(e) Displacement of the stapes in the oval window.

(f) Caloric stimulation of the middle ear.

(g) Eddy currents produced in the endolymph by slow movements of the ear drum and ossicles due to pressure changes in the middle ear.

(h) (Alternobaric vertigo) caused by pressure differences in the middle ear.

The theories of Melvill Jones and Lundgren are admittedly similar in their basic dynamics; that is, the changes of pressure in the middle ear affect the pressure loading of the endolymph. There is a subtle difference, however, which in hydraulics may be of importance. Melvill Jones spec fies, as does Lundgren, that the initiating factor is middle ear pressure changes, but he further defines the potential rtiginous effects as resulting from eddy currents in the endolymph, while Lundgren merely speaks of pressure cha s of a full bore nature upon the labyrinthine structures. He infers, as does Melvill Jones, upper respiratory infection involvement affecting the ability to ventilate the middle ear, in some cases with unequal pressurization. On the basis of the more specific definition as to cause as stated by Melvill Jones, these two theories are presented separately, although fundam tally they appear to be the same.

It would appear that the eddy curre ts of Melvill Jones and the alternobaric vert of Lundgren should be given the greatest consideration as poten ial etiological factors, although a combination of any or all postulates may be contributing factors. Extr vestibular components of the body related to spatial orient ion may also play a critical role in disorientation and vertigo in divers. The abnormal stimuli to the vis al apparatus, proprioceptive receptors, and unusual body pressures in a deep dive may cause disorientation when in the absence of light coupled with the semi-weightless state of the diver, he loses contact with the surface, and does not know which way is up or down. Several divers have been drowned in dark and dirty waters apparently for these reasons. W.J.White[17] at Cornell University, New York, placed subjects in a sub ed gimballed chair. With their vision occluded, they could never tell which way was up when exposed to the gim ed movement.

Obviously, serious vertigo is a grave menace to the diver. Vomiting into the breathing apparatus has fatal connotations; while prolonged disorientation could lead to an exhaustion of oxygen and subsequent drowning. Lundgren observes that vertigo is sufficiently common among divers and of such potential severity to deserve a wider recognition among workers in the field of diving medicine. We subscribe to this observation.

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DISCUSSION

DOBIE. I have not been impressed with 'pressure vertigo' as a common cause of disorientation in aviators, as distinct from divers who of course experience much greater pressure changes. Could the speaker comment on his experience of the incidence of 'pressure vertigo' associated with the Valsalva manoeuvre since there would be a more direct readover to the aviation environment?

BLOOM. Although I agree that it is theoretically possible to postulate an association between the Valsalva manoeuvre and vertigo, in my experience with divers and diving operations I have not seen examples of this association. In many instances, divers who feel that they must frequently and vigorously employ the Valsalva manoeuvre are anxious to a higher degree than normal. Commonly these individuals are predisposed to hyperventilation, a condition which must also be considered in attempting to explain the associated vertigo.

KURSCHNER. Can you give me some details on ocular disturbances you noticed in divers requiring decompression treatment?

BLOOM. The classical and commonly described ocular disturbances associated with decompression sickness include visual field cuts, scotomata and nystagmus. These are considered serious signs of decompression sickness and are much more commonly seen in civilian divers who completely disregard proper decompression procedure than in Navy divers on standard operations.

BENSON. In discussing vertigo produced by changes in ambient pressure in flight I think it is important to differentiate clearly between 'pressure' or alternobaric' vertigo and vertigo which is a symptom of decompression sickness. Pressure vertigo is commonly caused by the sudden equilibration of middle ear pressure and a transient disturbance of the distribution of endolymph within the membranous labyrinth. The vertigo is normally of short duration and reflect the return of a cupulae from a deflected to neutral position. The vertigo of decompression sickness is but a symptom, and the associated nystagmus but a sign, of bubble formation and impairment of blood supply to the vestibular apparatus, vestibular nerve or brain stem nuclei. It is essentially a more sinister condition requiring early diagnosis and treatment.

THEORY OF DEVELOPMENT OF REACTIONS TO WHOLE-BODY MOTION CONSIDERED IN RELATION TO SELECTION, ASSIGNMENT, AND TRAINING OF FLIGHT PERSONNEL

by

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A speculative theory, dealing with the development of reactions to whole-body motion, is outlined. Functional aspects of reactions at several stages of maturation are considered in relation to conditioning mechanisms which are, in turn, related to individual differences in development of motion reactivity, personality, and cognitive function. Unnatural feedback resulting from passive motion is discussed in relation to different control tasks performed in different job assignments and in relation to individual differences in reactions to motion. Adaptation to the unnatural whole-body movement of flight is considered in this context and in relation to experiments illustrating that substantial changes in reactions to motion can be accomplished through habituation. Aviator selection tests, such as the BVDT, personality tests, and flight aptitude tests, and several categories of training are considered in relation to the theoretical constructs.

I. INTRODUCTION

While observing a large number of individuals under unnatural conditions of motion, one cannot avoid being impressed by the range of individual differences in immediate reactions. Some men enjoy stimulus conditions that literally incapacitate other individuals. The unnatural conditions of motion referred to here do not necessarily involve high magnitude accelerative forces and this inquiry is not concerned with the disruption of behavior or mental processes as a result of overwhelming inertial forces. Rather, it is concerned with force and visual environments that introduce unnatural patterns and sequences of sensory information regarding spatial orientation. Such situations arise in air, sea, and land transportation.

In addition to individual differences in immediate reactions, there are also striking differences in long-term adjustments to motion. For example, of 695 men interviewed in a destroyer escort squadron, 13 per cent were habitually seasick, 10 per cent were often sick, and 38 per cent were occasionally sick (1). In the Pensacola naval aviation training program about 20 per cent of the candidates became airsick within the first ten flights in dual-control training. Of these, about 3 per cent continue to experience sickness problems after they move on to the training phase in which they have sole control of the aircraft. Aside from sickness, reactions to unnatural motion can influence other important functions such as fine sensory-motor coordination in flight (2, p. 1116-1120, 3, 4). The fact that a 5-minute observation of reactions to head tilts during rotation at 10 or 15 rpm can be used to considerably improve prediction of future flight attritions strongly suggests that these immediate reactions to motion have far-reaching significance (5, 6).

In considering potential reasons for these pronounced individual differences in initial reactions and in adaptability to motion, it is necessary to consider not only the dynamic response of the sensory detectors of motion but also the natural functional significance of controlled natural motion to the evolution and development of man. We are therefore faced with the classic problem of dealing with inborn characteristics as well as developmental conditioning. Man and other animals have three basic responses to imminent danger: 1) freezing, 2) running away, or 3) running toward (to attack). Each of these requires control of motion coupled with physiological preparation for action, and it is likely that our immediate reactions to unnatural motions are to some extent built in. On the other hand, there is a good case for developmental conditioning of our reactions to motion, and it also seems likely that some of our reactions to motion as adults are attributable to early experiences at various stages of development.

It is the purpose of this paper to introduce a highly speculative theory in an attempt to coordinate and interrelate a number of different lines of scientific inquiry which are relevant to an understanding of the individual differences in immediate reactions to motion and of differing abilities to adjust to unnatural motion. It is believed that an understanding is necessary in aviation medicine for such purposes as selecting efficient training programs, predicting with a degree of certainty that a ground or even a flight-based conditioning program will be effective in an operational setting, prescribing mental sets and conditioning which will afford protection against undesirable motion effects without inducing undesirable behavioral side effects, maximizing selection of those who have prerequisite adaptive potential, and improving the effectiveness of flight simulators and trainers. Perhaps of greater importance is the fact that an improvement of our understanding of individual differences in emotional reactivity and in human adaptive mechanisms is relevant to most of man's important activities.

II. DEVELOPMENT OF REACTIONS TO MOTION

A. Natural Passive Motion

Accurate voluntary motion is highly important to the survival of man and animals. However, early in life, whole-body motion is, for the most part, passive. Prenatal influences on the development of reactions to motion are difficult to assess because the peripheral and central nervous systems are under development. Although the possibility for early imprinting exists because of the natural activity cycles of the mother, the potential influence of early postnatal events is more obvious.

Groen (7,8) has shown that there are orderly vestibular sensory messages concerning the rate of motion at birth. The dynamic characteristics of these sensory-motor reactions change during the first few postnatal weeks in an orderly way,

presumably as a result of the developing central nervous system and visual system which exert more control over vestibular afference and eye movements. Thus, infants moved early in life have sensory information which can be associated with other experiences related to the movement. According to Smith and Smith (9) postural movements comprise the most primitive motion system in both phylogenetic and ontogenetic development. Controlled movement is one of several criteria for differentiating plant and animal life. "The older centers of the brain are organized principally for regulating postural mechanisms and integrating it with respiration and other vital functions" (9, p. 6). Change in orientation relative to gravity makes demands upon both cardiac output and the skeletal muscles. Changes in position and in the state of motion influence respiration, pooling of blood, and temperature control. Different activity levels place varying demands on the energy content of the blood (cf. Steele, in 10).

Coupled with these considerations is the fact that certain fears seem to be present at birth; that is, they are built in. For example, sudden lack of support (fear of falling) and loud noises produce a clutching or grasping reaction in very young children. It is perhaps very significant that these startle reactions are reported by Grastyan to be very easily conditioned (11, p. 246-247). Considering these bits of information in combination, it appears quite reasonable that respiratory, cardiovascular, and neuromuscular responses to changes in position and to motion develop not only by inherent maturational processes, but that they are also shaped by early conditioning. It is proposed that the magnitude of these physiological counterparts of emotion depend, at least partially, upon conditioning during the early passive stage of motion, during early ambulatory activity, and during later exploratory behavior. It is also, of course, quite likely that there are inherited differences in reactivity.

Parental handling involving sudden and unexpected changes in position might condition in an infant exceptional respiratory and cardiovascular responses to sensed motion. Thus, sensed passive motion might be conditioned to produce unusual respiratory, neuromuscular, and cardiovascular changes if a parent characteristically moved the child suddenly without sufficient warning. In addition, emotional reactions may be conditioned to sensed motion in other ways. Infants are moved early in life for feeding and in order to change diapers. A tense, harried mother may well predispose an individual toward later problems with unnatural motions. The fear of movement could even generalize to a fear of investigative activities and thus predispose a person toward inactivity, lethargy, and low-drive states.

In contrast to the situation in which a parent inadvertently exposes an infant to numerous sudden, unexpected changes in position, let us consider the converse situation. Gentle handling in which pleasurable cutaneous stimuli signal the onset of gentle motion, such as in feeding accompanied by gentle rocking, might well predispose an individual to a quite different set of reactions to passive motion. Under such circumstances, the gentle warning permits anticipation of respiratory and cardiovascular demands which are therefore not excessive. Under these circumstances, efficient respiratory and cardiovascular reactions to passive motion could develop in early life. Such an individual exposed to unnatural passive motion at a later date might well prove to be more adaptable to motion than is the person who was frequently exposed early in life to sudden fear-producing movements. Is it possible that some of the differences among the calm, highly efficient person, the highly energetic, fairly efficient person, the hyperkinetic, inefficient person are partially determined by these kinds of differences in developmental conditioning?

Also relevant to considerations of the passive-motion stage of development is the fact that Navajo infants reared on cradle boards, with little opportunity to exercise their legs, walk as early as do Navajo infants reared with full opportunity to use their limbs. In contrast to this, orphanage infants who were cared for in regard to feeding, sanitation, adequate lighting, and ventilation but who were not moved about were retarded in regard to locomotor development and several tests of early intellectual function. Despite signs of later maturational recovery, the potential influence of early conditioning on a variety of functions is suggested (cf. 12, p. 60-64).

B. Early Voluntary Whole-Body Movement

With further maturation, voluntary movement becomes more and more a natural activity. It is perhaps significant that 2-year-old children recognize a triangle that has been rotated through 120 deg from the training position only after a head rotation, whereas older human subjects do not need to make the head rotation to recognize the figure in the two positions (13, p. 346). Although there is some evidence that spatial abilities are a sex-linked recessive inherited trait (14), there is also considerable evidence that developmental conditioning involving motor control of the head and body will have a considerable influence on the development of spatial and numerical abilities in children. Orienting or pointing toward something desired is an early form of communication involving spatial localization.

> Things heard become things to look at; things seen become things to grasp; things grasped become things to suck, etc. In the course of such coordination, inputs from the distance receptors, and especially the eyes, acquire control over motor activities. Intentions emerge, means are distinguished from ends, interest in activities and in objects develops, and behavior becomes more and more variable and adaptive. All this happens presumably as central processes become coordinated and redifferentiated. The sensorimotor period ends when the child is about 18 months old and the sensorimotor schemata and imitations begin to become internalized as images. During this same sensorimotor period of 18 months, objects acquire permanence while causality, space, and time become objective. (From Hunt, 12, p. 354, in his discussion of some of Piaget's concepts)

It is reasonable to suspect that any or all of these developmental activities may be affected if exceptional emotional responses are connected with movement; in other words, if the child is afraid of movement. Smith and Smith (9, p. 284-291) have shown that association between voluntary acts and control of passive motion can be learned in quite young children. Interestingly, these children showed a variety of emotional reactions, including some extreme ones, to passive motion.

Early attempts at [illegible]ing and walking are inefficient, with mistakes resulting in occasional punishment from falling.

Rewards occur as goals are achieved, and secondary reinforcements to rewards come from the reactions of parents when the motion is successful or desirable. During this period, associations begin to develop between intention, voluntary initiation of motor acts, and feedback from the senses pertaining to perceived space and movement relative to distant objects.

As these transport movements continue to develop, the potential of conditioning or imprinting, and there is a narrow distinction here (11, p. 91-92), remains. Transport movement sometimes elicits violent reactions from parents when, for example, a valued object is broken by the infant. In such cases, loud vocalizations from the parent which are fear inducing, violent repositioning which is fear inducing, and physical punishment which is fear inducing, sometimes result from the transport movement. The vagaries of early life may well condition emotion and anxiety to voluntary motion. The initiation of motion in response to external stimuli or in the exploration of the external world is an early form of planning and communication with the external world. The images of the consequences of behavior are under development (15, 16). The natural feedback resulting from motion, and the external feedback imposed by parents or by accidents together influence image development, volition, and other cognitive functions. Relations between speech and control of motion undergo a developmental sequence in which the child responds to simple commands, then initiates movement by his own speech, and as skill is developed, performs in silence (cf. 15-18).

Abnormally high cardiovascular reactions associated with motion may even reduce ability to learn as exploratory behavior develops. Dicara, Weiss, and Miller (19) have reported that conditioned heart rate affects learning in animals, high rates adversely and low rates favorably. It has been shown (19-21) that man can learn to control heart rates, and the training to reduce heart rate appears to reduce emotionality as well (19). In other words, it appears that it is possible to condition in some individuals voluntary control of a number of physiological activities ordinarily believed to be not subject to voluntary control (21). Kimble and Perlmuter (15) have suggested, and have given evidence in support of the suggestion, that the acquisition of control over involuntary processes is always accomplished with the aid of supporting responses already under voluntary control. Such training might well prove effective in adapting individuals to stress situations in general, and to motion stress in particular. Equally relevant is the fact that these reactions are subject to conditioning late in life, and therefore it is quite reasonable to assume that they are also shaped by conditioning early in life. In this connection Rogov (22, p. 84) has shown that vaso-reactions are more easily conditioned in 3- to 5-year-old children than in 8- to 10-year-old children.

As maturation progresses, the matching of sensory feedback with expected feedback is part of a learning process which reduces unnecessary muscular effort and produces more efficient movement. Piaget has described tendencies for children to practice particular sensory-motor skills with much evidence of pleasure and then to stop when the skill is mastered (12, p. 176-179). An early experiment of Davis is relevant to the increased efficiency of skillful performance. In a simple weightlifting task in which children and adults were compared, Davis found that the most important difference between the adult and the child was the type of distribution of muscular activity in the two groups. In adults, muscular activity was more restricted to the responding arm than in children who showed more generalized muscular activity. Davis suggested that the acquisition of voluntary control is a part of the mass action-differentiation sequence (15, p. 373-374).

With further maturation, route-finding and returning home become a necessary part of life. Although there is a considerable evidence that homing and migratory activities of some species seem to be built in, i.e., are instinctual (23), there is also the distinct possibility that training along the way can exert control over this behavior in all species, especially those in which homing behavior is not so clearly inherent. Early experiences could affect route-finding and homing activity, the extent to which it is attempted and if attempted, the rate at which it is learned. Excessive emotional overlay possibly reduces both the exploration and the learning.

The development of the route-finding ability seems to involve the nondominant parietal lobe in man (24). Individuals without vestibular function are unable to retraverse different paths while blindfolded, whereas individuals with vestibular function show good accuracy in this activity (24,25). Thus, in normal states the visual and vestibular systems work together in the development of comprehension of spatial coordinates (24). Individuals with lesions of the nondominant parietal lobe but with intact vestibular organs are unable to retraverse paths normally even with the aid of vision (24). According to Luria, "Disturbances of the lower parietal lobe (cortical basis of spatial analysis and synthesis) lead to a loss of spatial orientation and the ability to count and comprehend complex grammatical constructions. This means that these three different behaviors are all based on a single factor - simultaneous spatial analysis " (26, p. 90). Thus it is possible that a severe curtailment of this stage of development by parental restrictions or other external agencies could influence development of a variety of important mental functions. It is perhaps quite significant that paper and pencil tests of spatial relations have been for years one of the better predictors of the success of naval flight training (27).

C. Mature Voluntary Whole-Body Movement

At maturity, orderly sequences of sensory messages occur as a consequence of each voluntary movement, but they are not necessarily consciously perceived. Movement involves messages from the eyes, the auditory and nonauditory labyrinths, the muscles and joints, which occur in set contemporaneous and sequential patterns. These messages contribute to the coordination of complex movements and activities. The use of this feedback without our conscious awareness seems to be amply demonstrated by the 'surprise' of subjects when they first participate in experiments which involve delayed feedback.

The effect of delayed auditory feedback on speech is a well-known phenomenon, but delayed visual feedback with concurrent performance also produces severe disturbance in regulation of movements (9). One of the effects of delayed visual feedback is to produce a repetitious movement comparable to the artificial stutter in speech produced by delayed auditory feedback. Emotional disturbance and frustration produced by short-interval delay are reported by Smith and Smith (9) to be even worse than the effects of most geometric displacement. "These effects range from minor emotional disturbance and frustration through dizziness, giddiness, faintness to nausea and illness" (9, p. 108). They report that gross anxiety and depression are not uncommon among subjects who try to wear inverting lenses which reverse objects for even a short

period of time.

Thus, with maturity and practice movements which were previously accomplished with generalized muscular exertion and direct attention have become differentiated and only those components necessary to efficient automatic function remain. As much as possible, responses which can proceed without consciousness recede from consciousness (15, p. 373-377). The process of correcting a faulty golf swing in a skilled golfer involves reviewing all those various aspects of the response which have receded from consciousness to detect a faulty component. A comparable degree of skill is possessed by most of us in walking and running, et cetera, and we expect our voluntary commands to movement to accomplish some end result without our having to consciously check feedback on each component of movement. In long continued motion such as running, periodic repetitive patterns are set up by the inner ear organs, the joints and muscles, with the eyes foretelling necessary alterations to maintain efficient rhythmic motion in which muscles work synergistically. In some animals while running over rough terrain, the head is amazingly well stabilized. The periodicity of foot impact with the Earth is probably stored on a short-term basis to aid in the rhythmic motion and in the rhythmic demands on the muscular, cardiovascular, and respiratory systems. Thus a temporary neural copy of rhythm may be a form of quick adaptation necessary to efficient coordinated movement in which rhythmic demands are met with efficiency to steady the head and to reduce fatigue. If so, the saccular organ may provide an important input to brain centers apparently involved in rhythm copy (17).

von Holst (in 13, p. 497) has introduced terms that are now becoming commonly used in discussing voluntary movement and the effects of unnatural sensory feedback occasioned by the movement. He distinguishes among exafference, reafference, and efference. Exafference refers to all sensory messages initiated by the external environment, whereas reafference refers to afferent information produced by muscular activity initiated by the individual. Thus exafference is independent of motor impulses, whereas reafference is a term reserved for sensory activity that arises as a result of motor actions. von Holst assumes that the voluntary command (cf. Greenwald, 16) to commit an act, in addition to sending motor impulses that initiate the muscular movement, also sets up somewhere in the nervous system what he calls an efference copy. Thus, the voluntary initiation of an action sets up an efference copy (image), and the reafference resulting from this movement is compared with this efference copy. With these concepts, it is possible to explain a number of experimental facts that show we have impressive ability to distinguish motion of the environment from our own motion (cf. 13, p. 497-504). For example, in voluntary movement of the eye, we do not see the environment move, although images track over the retina as though the environment has moved. The voluntary eye movement is presumed to set up an efference copy, and the reafference from the retina matches this efference copy, nullifying it, and signifying that the surroundings have not moved. If the eye muscles are narcotized and the voluntary attempt is made to move the eyes, a different situation results; in this case, there is an efference copy but no moving retinal images, since no eye movement has occurred. Under these circumstances, according to the von Holst theory, the environment should appear to move in the direction of the voluntary effort to move the eyes. This is in fact what happens. The phenomenon called micropsia when the accommodative mechanism is narcotized can be similarly predicted. von Holst, of course, was anticipated by James (28), Mach (29), and others in consideration of volition and "images" set up by voluntary acts; but his work has served well to extend and reactivate some old ideas.

The point is that in the mature individual, motion is typically initiated voluntarily. The sensory feedback or reafference is compared in some way with expected return patterns, but this is largely on the subconscious level in natural movements. Thus, many sequences of actions take place without any attention to components until some breakdown occurs. In this case, attention is directed to the action and a correction is made.

In the pursued or pursuing animal or man, a mistake or breakdown in coordination can cause injury, loss of food, or other severe embarrassment, and the process of recovery from a misstep may require quick emergency reactions. In modern man highly skillful motion is frequently required in competitive sports activities. Here failure may produce physical injury, a sense of failure, or "success may produce confidence." Individuals may seek aviation training to extend their exploitations of "good coordination" or to make up for failures. Thus, a breakdown in complex patterns of well-learned voluntary movement may be responded to with emotional and neurovegetative overtones dependent upon innate mechanisms as well as upon associations between control of movement and emotion developed over the years. In the context of these considerations about how our reactions to motion may develop, let us consider some of the situations to which man is exposed when he is required to perform on an unstable motion base.

III. INTERRELATIONS BETWEEN REQUIRED PERFORMANCE AND REACTIONS TO UNNATURAL WHOLE-BODY MOTION

A. Unnatural Passive Motion: Passenger Inactive

Examples of the condition under consideration in this section are passengers in any moving vehicle who are motionless relative to the vehicle and who are also not in control of the vehicle. What are some of the reactions, and what are some of the factors that control these reactions? Reactions may include perception of movement; eye, head, body, and limb compensatory movements; changes in respiration; sweating; pallor; fear; drowsiness; depression; nausea; and vomiting. Contributing to such reactions are the individual sensory detectors of motion and their dynamic response to the motion condition, the sequential and concomitant pattern of sensory inputs from various sensory channels, the previous exposure to similar motion stimuli, the assessment of the current situation, the individual's reactions to motion stress in particular, and perhaps the individual's reaction to stress in general.

The dynamic response of individual sensory detectors is clearly important here. The motion must have characteristics that simulate the sensory detectors or typically no reaction will occur. For example, high-magnitude linear velocity will not elicit a reaction if the man is encapsulated and cannot see relative motion between himself and some other reference system. When stimuli are adequate, then patterning of sensory inputs and intensity of inputs from individual channels become critical. If the patterns of individual intensities have been frequently experienced without previous emotion-evoking associations, then an orienting reaction (attention or inspection) may occur initially, and after a few repetitions, most of the

unnecessary aspects of the response may drop out, and the necessary responses may soon become subconscious if they were not so initially. What is necessary are those response patterns that tend to keep the body sufficiently stable relative to the moving platform to avoid injury or threat of injury, i.e., to provide a feeling of security, and these compensatory reactions are not typically consciously perceived.

Patterns of input that evoke emotional reactions can be quite subtle. A gentle rocking motion may be quite soothing and may even be soporific if a person is on a swing or ship. However, exactly the same rocking motion may elicit intense adverse emotional responses if the person is in a hotel and has recently encountered an earthquake. Thus even in passive involuntary motion, the total reaction to the sensory input it produces depends upon the expectation of that input pattern in the context of the particular environment as well as upon the frequency and quality of previous experience with the particular motion pattern. Input patterns and sequences are compared with expected inputs, which depend upon the individual's assessment of his current situation as well as upon his previous experience with similar motions.

Assessment of the current situation can also influence the perception of motion in addition to influencing the immediate emotional consequences. For example, people encapsulated in a lighted room which is known to be capable of rotation about an Earth-vertical axis frequently report commencement of rotation before rotation commences. These reports involve no sign of emotion. On the other hand, such subjective experiences rarely occur in an enclosed room which is known to be firmly fixed to the Earth, and when they do occur under these circumstances, they they are usually accompanied by emotional reactions. One important part of the treatment for Ménière's disease is to alleviate the emotional concern brought on by the experience of motion (30).

A passive motion may initiate sensory inputs that call for mutually antagonistic motor reactions. For example, a sinusoidal angular oscillation of sufficiently low frequency produces a semicircular canal response that can be phase advanced relative to the stimulus by as much as 2 seconds, depending upon frequency of oscillation. In a recent experiment (31), severe problems with motion sickness were encountered during sinusoidal oscillation about an Earth-vertical axis when the vertical canals were stimulated, but not when the horizontal canals were stimulated. The phase advance of the vertical canal response is about twice that of the horizontal canal response in man at the stimulus frequency used (0.04 Hz). The point of reversal of rotation (endpoint) is confusing with this oscillatory stimulus because the subjective velocity and subjective displacement sensations seem to be out of phase. This probably is caused by phase differences among various sensory detectors of motion. Mach (29) proposed that such phase differences might account for some motion sickness and he was probably right. When the endpoint of yawing, rolling, or pitching, as detected by this sensory system, precedes the actual endpoint by as much as 2 seconds, while other sensory input sources with different dynamic characteristics indicate turning points at other points in time, then there are demands for preparatory bodily adjustments at different points in time which require an adaptive change in the central nervous system. If external visual reference is excluded, then the absence of this natural source for initiating anticipatory adjustments to upcoming demands for whole-body responses places an additional handicap on the central adaptive mechanism. Thus with whole-body motion in which man is an inactive passenger in a moving structure, the emotional consequences depend upon the immediate assessment of the current situation, the discordance of sensory inputs, previous experience with the motion, and developmental conditioning. The assessment can make the difference between almost no reaction and an extreme emotional reaction to motions that are, in essence, benign. Other motions, however, may introduce a discordance of sensory inputs. The discordance is determined by the dynamic response of sensory systems to the motion stimulus. In the example given, different sensory phase relations to a simple sinusoidal stimulus led to the discordance. Such discordance would be frequency dependent, and probably not very great except at certain frequencies where phase mismatches are especially prominent. This should vary somewhat between subjects because there are pronounced individual differences in parameters of vestibular response systems (32,33) and it also would vary, depending upon the canal system stimulated. It is important to note that these mismatches in timing are closely analogous to delayed visual or auditory feedback experiments (9, p. 291), except that in this particular example the action was not voluntarily initiated.

For more complex passive motions, discordance can be more than a phase mismatch in which essentially the same reaction is required with only a mix-up in its timing; it can be a discordance in which reactions in different spatial planes are called for at the same time. It is then analogous to the geometric displacement experiments (see reviews in 13, 34). The magnitude of a planar mismatch presumably would depend upon both the magnitude of the planar angles and the magnitude of the individual sensory signals indicating the planes (cf. Guedry in 10). These forms of mutually incompatible sensory messages are presumed to evoke immediate limbic system reactions due to their novel nature. When the mismatching signals are sufficiently strong, they will evoke immediate emotional reactions independent of the assessment of the current situation because the reaction incompatibility per se represents an emergency condition without the requirement for additional comparison with stored information.

The magnitude of the immediate emotional reactions, however, would depend upon the general anxiety state of the individual and also upon past associations, throughout his development, with motion stimuli in general and with similar unnatural motion stimuli in particular. Ability to adjust to such stimuli may be inversely related to the degree of the emotional reaction. It is important to note that many of the conflictual sensory inputs referred to here are not consciously sensed as conflicts, for the vestibular sensory system is normally a silent partner in coordinated movement. Thus, perception of the vestibular inputs in these conflictual situations may be described as "confusion" or as a "funny feeling" and not as a clear, conscious perception of moving in two different directions at the same time.

Passive motion with the man continually inactive is not a typical state for most passengers or crewmen in various modes of transportation. If the person were completely passive, the situation would not involve those inferred processes of voluntary behavior which von Holst refers to as the matching of reafference and efference copy. For this reason, prolonged exposure and adaptation to motion in this way may transfer only minimally to situations in which comparable sensory inputs are coupled with voluntary movement. However, it is to be noted that if passive motions are sufficiently periodic or predictably repetitive, then a certain amount of anticipation may develop and permit anticipated sensory patterns to be compared with sensory inflow. If the subject has external visual reference, as does the transported Navajo child (12, p. 60), then

opportunity to compare inertial sensory data with veridical visual reference would be augmented. This could improve the immediate reaction (by improving accurate anticipation and reducing inefficient preparatory responses), improve the ability to adjust, and perhaps afford some favorable transfer effects to other conditions of motion.

B. Unnatural Passive Motion: Passenger Active

This section deals with reactions of passengers actively moving about in a vehicle that they are not controlling. Examples include active passengers or crew members on board ships at sea, aircraft in flight, rotating space station simulators, et cetera.

As indicated earlier, during voluntary movement in a natural environment, highly ordered contemporaneous and sequential patterns of sensory messages occur as a consequence of voluntary movement. The orderly patterning is determined by the sensitivity and dynamics of the sensory movement detectors themselves. Sensory information about relative position and velocity of the limbs and about the position and movement of the whole body relative to the Earth is available consciously, and thus normally monitored for reliability checks as motion progresses. However, these checks are typically so automatic that we are not consciously aware of their use until an error in movement is actually perceived. Small errors are typically corrected without conscious awareness of the correction in the process of approaching a goal.

Thus voluntary movement on a moving platform introduces a new consideration. Initiation of a voluntary motion sets up an image (efference copy) of expected upcoming afferent patterns (reafference). Because of the moving platform, the reafference received from vestibular and proprioceptor systems as the movement progresses may not match the efference copy at all. The highly conditioned expected sequence of events does not take place, at least as indicated by some of the afferent data produced by the motion. These novel (strange) patterns are especially at variance with expected feedback in the absence of external visual reference (information on relative movement between platform and Earth) which, when available, can revise initial expectations at the outset or as motion progresses. This, then, is an additional challenge to that produced by passive nonvoluntary motion because the ability to carry out a voluntary action is threatened. In contrast, a man tilted passively on a rotating platform would have some conflict between otolith and canals in the absence of vision; with visibility of the internal capsule, he has conflict between vision and the semicircular canals. With voluntary head movement, he has conflict between efference copy and semicircular canal data whether vision is present or not.

"Behavior is such as to bring the expected future condition of the organism into congruence with the desired condition" (Gerard, in 11), and this has been challenged. Competence to sustain efficient voluntary movement within the spatial environment is an ability that can be critical to survival of all higher forms of life, even including modern man with his many means of transportation. The magnitude of the adaptation problem faced by the man in this situation depends upon the motion characteristics of the platform, their consistency, the tasks he is attempting to carry out, and his developmental conditioning.

His emotional reaction to the situation would be influenced by the same factors that control emotional reaction in the passive situation, but it would be additionally influenced by his developmental conditioning in relation to achievement of goals, since in this case the motion is voluntarily initiated and an end result is expected. That motivation and drive states are adversely influenced in many individuals under these circumstances has been frequently indicated (cf. 35). As reported by Bruner in his interview with personnel of a destroyer escort squadron (1), the primary operational hazard of this condition does not come as much from vomiting as from the fact that early in the syndrome, attitude toward work becomes negative, drowsiness sets in, and vigilance and individual initiative are degraded.

C. Unnatural Motion: Actively Controlled

Pilots of modern means of transportation such as aircraft voluntarily expose themselves to highly unnatural motions. The sensory feedback generated by maneuvers in aircraft and other vehicles may have any of the several forms of discordance indicated in the preceding sections.

There are a number of differences between this situation and that in the preceding section. First, the pilot is exposed to certain amounts of passive motion by virtue of turbulence, but he does have the option of responding to this passive motion and initiating voluntary compensatory actions which change the stimulus itself. In initiating a maneuver voluntarily, he anticipates feedback and he eventually establishes an acceptance zone; i.e., a range of acceptable deviations from the exact expected result. He is provided a set of additional sensors, flight instruments, with which to check his orientation and state of motion. The highly experienced pilot may not have an immediate awareness of his anticipation of the results of his control actions until unexpected sensory feedback occurs, but then he is keenly aware of any discrepancy between his expectations, his immediate perception, and his flight instruments. With sufficient experience he adapts to the discord among various sensory-motion detectors, and he learns that certain mismatches between his immediate perceptions and his instruments are desirable, but when this new state of normality has developed, he cannot afford an additional level of adaptation. Perhaps the most important differences between the pilot and the crew is that the competence of the former's decisions and control actions are crucial to his survival, and he knows this. Thus, the difference between the pilot and the crew is in some respects comparable to the difference between Brady's executive and nonexecutive performers (36). The adaption problem for the pilot's job should not be regarded as necessarily more demanding than that of the crew, but it is different and may require personality differences. The crew has the advantage that the decisions on immediate control of the aircraft are not required, but they can only indirectly anticipate motions or initiate protective reactions. The pilot has the advantage that he can anticipate motion and take actions that alter the state of motion. He has the disadvantage of a sense of responsibility for his actions and can build up an anxiety connected with his competence to meet the demand.

It is reasonable to believe that the limbic system, which integrates disparate functions into an orderly whole (37, p. 135), which is involved in laying down neural traces of the contingency of relationship between one stimulus and another,

which is involved in ascertaining novel stimuli and which is involved in the production of fear, nausea, sweating, respiratory changes, and fainting when the stimuli are threatening, is brought into action by these unnatural patterns of sensory input coupled with the task of controlling the aircraft. If we presume that, in some individuals, this situation can through the developmental conditioning elicit abnormal arousal states that disrupt the normal function of the hippocampus and amygdala, then both immediate and long-range ability to adapt to the flight task may be severely limited, much as hippocampal stimulation can induce severe fixation of attention (37, p. 121-122), and lesions in these areas limit recent and immediate memory and the learning of sequential tasks (37).

IV. SOME EXPERIMENTS ON HABITUATION OR ADAPTATION TO UNNATURAL STATES OF MOTION

Habituation to various states of motion is a complex process. First, the total reaction to unnatural motion involves many subsystems, and second, there are many states of unnatural motion; e.g., unnatural immobility produces measurable change, as does unnatural mobility.

If an individual is fixed relative to the Earth and the entire visual surrounds move, a variety of reactions can be elicited, including perceived whole-body movement, nausea, and even vomiting (38). This appears to be a case involving discordance between the inertial senses indicating no motion relative to the Earth and the visual input indicating motion. It is relevant to flight-simulation devices in which the pilot's control moves the visual surrounds while the pilot remains stationary. With such devices, it has been found on several occasions that experienced pilots encounter much more disturbance than do beginners (10, p. 49-50). Introduction of some inertial feedback in the situation reduces the disturbance. This suggests that pilots develop strong associative bonds between control actions and anticipated visual, vestibular, and proprioceptive feedback. In other words, they develop new matches between a pattern of reafference and efference copy. The visual flight simulator provides the visual reafference without the vestibular and proprioceptive counterparts.

On moving platforms there are a variety of effects, some of which have been reviewed in the previous section. Usually the visual surrounds move more or less with a person who is in the interior of the vehicle. However, if he moves voluntarily, then there can be relative motion between the man and the visual surrounds, both of which are moving relative to the Earth. This latter movement is detected only by the inertial senses when the person is encapsulated, but when external visual reference is available, for example on the deck of a ship, then the visual, vestibular, and proprioceptive senses can detect the movement of the whole body relative to the Earth, but only the visual system detects movement of the body relative to both the ship and the Earth.

Each of these several situations induces both physiological and subjective changes. It appears that something like reafference and efference copy and interplay between the visual, vestibular, and proprioceptive systems under various conditions of internal and external reference are important factors in controlling the kinds of adjustments which occur in various modes of modern transportation. In considering habituation or adaptation, it is not a simple matter to define what is meant by satisfactory habituation or adjustment. Understanding the relevance of all of the changes that occur during exposure to various states of motion to the functional integrity of the whole system is a prerequisite to defining this phrase, and of course, it is this understanding which is one of our major goals. However, let us define satisfactory habituation or adjustment as a change in the state of the organism that contributes to improved efficiency in dealing with the state or states of motion under consideration. This would include the reduction of misleading sensations and perceptions; the reduction of inefficient cardiovascular, thermal regulatory, and respiratory responses; the reduction of inefficient sensory-motor responses; the reduction of nausea and vomiting; the reduction of depression and discomfort; and, in general, an improvement in efficiency of motor control and psychomotor coordination and in a sense of well-being. We must recognize at the outset that a change which may be beneficial for one task performed in one state of motion may be inefficient and maladaptive for another task or for the same task in another state of motion. For example, reduction of a particular sensation or sensory-motor reflex as a result of repetitive stimulation is usually referred to as habituation or adaptation. This reduction may be beneficial if the sensation or reflex is misleading or irrelevant, but maladaptive if the person's task and well-being depend upon response to the sensory signal. There is evidence, however, that habituation may consist of several stages or levels, some of which actually may serve to reduce the frequency of maladaptive forms of habituation.

With this rather lengthy but partial list of considerations relevant to habituation, it may seem incongruous to restrict our consideration to the few experiments that are reviewed below. However, this is not an attempt to even partially review relevant experiments; it is, rather, a selection of a few experimental results that illustrate the fact that changes in the sensory, perceptual, and emotional reactions to unnatural states of motion do occur and that some of the factors controlling these changes are subtle, but nevertheless potentially within the realm of understanding.

The sensory information naturally provided by the vestibular system is angular velocity about any body (head) axis, angular-position (attitude) information relative to gravity, and probably linear-velocity information. The semicircular canals provide angular-velocity input during angular acceleration, and the otoliths provide attitude information during change in position (and also during maintained position). Vestibular linear-velocity information comes from a changing utricular input combined with a "no angular velocity" signal from the canals. It is this combination that is probably the <u>sine qua non</u> of the vestibular linear-velocity percept (39, p. 91). Although the first two functions are frequently separated for academic instruction, they almost never function separately in natural movement. Thus the angular velocity from the canals is normally coordinated with change in position information from the otoliths. Together they signal angular velocity about a head-axis which is located approximately relative to gravity by the otoliths. In natural situations, this information is typically supplementary to and interacting with visual information, tactual information, and muscle-joint information to maintain sequential sets of appropriate reflex actions during coordinated movement. In considering vestibular adaptive reactions, it is necessary to consider the natural functional interaction of these systems.

A. <u>Adaptation to Tilt</u>

In connection with adaptation to tilt, it is necessary to take into account that we have been constantly exposed

phylogenetically and ontogenetically to a 1 g-unit field and have spent much time in various orientations relative to this force field. Many of our activities do not demand perfect alignment with gravity and are carried out with the head or body deviated from gravitational alignment by some acceptable range of deviations. In running, we learn to line up approximately with the resultant of gravity and centripetal acceleration when we make fast turns or we fall down. It is true that some positions of static tilt lead to greater mean errors than others in adjusting a lighted line to vertical in darkness (40), but in most natural situations the error remaining from one sensory channel is corrected to within acceptable limits for equilibrium by supplementary information from several other senses. Thus, we are already adapted to many conditions of tilt, and in considering experiments on this topic, it is necessary to evaluate how some of the experimental situations which have been studied differ from our normal adapted state.

In many experiments the primary difference from the natural condition is that the tilt has been accomplished passively and slowly and the static position has been carefully maintained. In one such experiment, subjects in seated positions remained as motionless as possible in 12-deg lateral or backward tilt positions but were told that they were being smoothly returned to upright and to report when upright position was achieved. Previous to this, they had been shown that the device could move very smoothly. Within 1 to 5 minutes, subjects reported upright position (Guedry, 1949, unpublished). Upon actual return to upright, they felt as if they were tilted in opposite direction and required about the same length of time to report upright again. This latter effect has been demonstrated in several experiments in which misleading instructions had not been introduced (41). The results demonstrate that under static well-supported seated positioning without external visual reference, our position senses are fairly plastic. These adaptation effects, which are quite likely proprioceptive as well as vestibular, are short term, and there is no reason to suspect a retention of such effects from one day to the next.

In several water-immersion experiments (42-44), requiring repositioning of the body relative to gravity or pointing in the direction of vertical, judgments of verticality were found to be quite variable, and this variability, irrespective of the accuracy of mean judgments, suggests that the otolith system by itself does not provide highly precise or strong signals of verticality. In part, these experiments which have sought to remove all save the otolith signals have in some cases introduced complicating semicircular canal signals and in others, very slow positioning has reduced "change-in-position" information which the otoliths and canals would normally contribute.* To some extent, then, the large variability of judgments, which would signify poor verticality discrimination may result from the complicating canal signals, the absence of otolith change-in-position signals, and the lack of synergistic inputs from the other senses, rather than the paucity of otolith signals. Nevertheless, in these particular judgment situations the otoliths do not apparently provide a very compelling indication of verticality, and it is clear that flight can introduce even more confusing conditions for judgments of verticality.

In another class of experiments, visual fields have been tilted independently of the subject. Studies in which the subject is either statically positioned or is moved passively and slowly have shown that the main lines of the visual field influence the judgment of verticality (46). Pronounced differences in how much the visual frame dominates these judgments have been related to personality types (47). With highly specific instructions to subjects, these individual differences are diminished (48), but once again a plasticity of man in the judgment of verticality under essentially static conditions has been demonstrated. Witkin (49) found that training in situations with conflicting visual and proprioceptive cue situations induced some improvement in the "accuracy" of judgments, especially when the subjects were instructed concerning the available orientation cues.

In a related series of investigations, body "tilting" has been accomplished by keeping the subject upright relative to gravity, but by use of the centrifuge, a resultant inertial vector has been tilted relative to the body (29,50). Under these circumstances, the perception of the "gravitoinertial" vertical of a line of light lags considerably behind the change in the resultant vector (50,51). In this situation, the semicircular canals indicate rotation in a plane which is approximately orthogonal to the plane of the change in the resultant force. The slow change in the perception may signify a gradual adaptive shift from one frame of reference to another under some conditions (51), but under other conditions, the slow shift seems to depend upon dissipation of discordant canal information (52).

Experiments in which subjects have been maintained under unusual conditions of dynamic motion have not been typically regarded as "otolith habituation" studies, primarily because so many other sensory-motor interactions were also involved. However, when an individual is in flight, his readiness to shift to tilted visual frames such as a false horizon or to perceived "upright in the cabin" as gravitational upright may be even greater than the tendencies noted in some of these relatively static experimental conditions. In flight conditions the direction of the resultant force is frequently not in alignment with gravity, and hence it is frequently not perpendicular to the visible horizon. Moreover, the direction of rotation of the resultant vector may or may not be signaled by the semicircular canals, depending upon the particular flight maneuver. Under these conditions of highly unnatural combinations of inputs from the orientation and motion sensors, the dynamics of the perceptual judgments are not predictable from knowledge of individual sensory systems. Habituation to these conditions clearly involves more than adaptation to unusual otolithic stimulation. Habituation to complex spatial sensory inputs will be taken up in a later section.

B. <u>Habituation of Semicircular Canal Responses</u>

Discussion of vestibular habituation is frequently restricted to changes in vestibular nystagmus during repeated semicircular canal stimulation. During the course of simple, repeated rotation about an Earth-vertical axis in darkness, nystagmus declines when subjects are not kept mentally active (39, p. 10). Thus, as with other sensory stimuli, monotonous repetition of stimuli (which demand no attention for practical reasons) yields a decline in vestibular nystagmus. This is the

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*Location of body position relative to gravity by the otoliths may be partially analogous to position sense of limbs which decays immediately following movement (45). If so, some adaptation to tilt may be due to forgetting "change-in-position" information.

vestibular counterpart of habituation of the "orienting reaction" (cf. 22,53) which has been demonstrated for auditory, visual, and other sensory stimuli. It is a mechanism that provides the ability to attend to one thing without being distracted by all of the inconsequential stimuli that are constantly present in almost any natural environment. It has been repeatedly shown for many sense modalities that subtle changes in the stimulus will re-elicit the orienting reaction. The same seems to be true for nystagmus. What happens then is that there is some kind of monitoring going on, though it may be subconscious (54, p. 307f), which passes a range or band of various stimuli without diverting the individual from ongoing activity. When, however, a novel or danger-associated stimulus pattern is outside this acceptance band, there is an orienting reaction, or inspecting response. This process may involve selective suppression of vestibular afferent inflow to various centers, but it also involves an automatic assessment and classification of the signal in relation to the current situation.

There is an aspect of vestibular nystagmus and its relation to arousal which has been omitted from our consideration thus far. There have been a number of studies which indicate that sensory signals (e.g., auditory or visual) remain strong while an animal is attending to that specific signal source (cf. 22,53), but when another distracting stimulus or mental activity is required, the signals are reduced. More to the point of the present discussion, Hernández Peón and Donoso (in 55, p. 126-127) recorded from deep (subcortical) electrodes photic-evoked potentials from visual radiations in human subjects and noted that the evoked potentials were markedly smaller during difficult arithmetic calculations. As soon as solutions were reached, the evoked potentials recovered. It is curious then that vestibular nystagmus which is diminished after only a few stimulus repetitions (wherein the subject is no longer "aroused" by the vestibular stimulus) can be made to return in full intensity by assigning mental arithmetic problems (56). Arithmetic computations that divert the subject's attention from the vestibular sensations is at least as effective as is attending to and reporting vestibular sensations. This apparent paradox may well be due to the fact that in natural movement, the vestibular system must set off appropriate reflex actions to motion when the man or animal is engrossed with another task. The vestibular system typically functions as a silent partner in contributing to coordinated movements when the person's attention is on something else. Benson (personal communication) has recently shown that men oscillated angularly at frequencies up to 8 or 10 Hz still retain good visual performance for objects fixed relative to the Earth, whereas when the man is stationary and the object is oscillated, the visual performance drops off at oscillation frequencies between 0.5 and 1.0 Hz. In the former case when the man was oscillated, the vestibular system contributed to the performance but the man's attention was on the visual input, not the vestibular sensations. This is a typical example of vestibular function; vestibular coordination takes place without attention to the vestibular sensation because attention to an external vestibular eliciting agent is not naturally required. Vestibular signals are usually initiated when the person voluntarily moves the head or whole body. The voluntary initiation of the movement and the concomitant feedback from many other senses, which are more clearly under conscious voluntary control than is the vestibular sense, disguises the fact that we even have vestibular sensory data. Thus a person can voluntarily close or open his eyes, turn to see, close his ears, turn to better hear, touch himself or turn to touch something else, move to avoid being touched or hit, position a limb relative to the body or relative to gravity, or sequentially move limbs to walk, and all of these visual, auditory, cutaneous, and proprioceptive sensory data are subject to a degree of conscious voluntary control which is necessary for the person's commerce with the environment. But most of these same acts involve stimulation of the vestibular system, which provides sensory data without conscious awareness and which probably functions best when its contribution is not a matter of conscious awareness. When a person is highly active mentally or is attending to other sensory inputs, as for example in the act of pursuing game, vestibular reflex input to coordinated "automatic" movement must be at its peak, and attention to vestibular sensations must be minimal. In this context, it is not surprising that mental arithmetic enhances vestibular nystagmus even though it distracts the person from attending to vestibular sensations.

From these considerations, several points emerge: 1) Vestibular sensations in a natural environment are less subject to conscious awareness and purposeful conscious control than are those of the other senses relevant to orientation and motion. 2) Mental arousal heightens vestibular reflex action even when attention to vestibular sensations is irrelevant to the task at hand. 3) Reduction of vestibular nystagmus through "attention habituation" of this type is not an indication that a person will have suppressed nystagmus reactions to semicircular canal stimulation in the flight environment. 4) Much of the vestibular stimulation in flight is unnatural, and it sets off reactions that are functionally useless. Because these stimuli are novel, they at first evoke arousal that potentiates vestibular reflex actions. With more experience in flight, the acceptance band is widened and fewer vestibular signals elicit these nonfunctional reactions. 5) However, heightened mental arousal for any reason, including perceived threat, will potentiate the elicitation of vestibular reflex actions when these reactions have been reduced only by attention habituation. Increased unnecessary vestibular reactions or the tension created by their potentiation and suppression can interfere with fine motor control (3,4,31).

There is another form of response change that occurs during a prolonged semicircular canal stimulus. During constant angular acceleration, nystagmus peaks and declines and sensation peaks and declines even more quickly (39,57). Following such a stimulus, there is a reversed or secondary reaction. These response characteristics are at variance with theoretical estimates of cupular responses and have been regarded as evidence of adaptation. Several models have been proposed to account for the effects (in 10, p. 363-380). These kinds of adaptation signs seem to occur during high arousal levels (57), and they also occur when arousal is not maintained throughout the response (39, p. 83). The latter point is important because it indicates that the occurrence of the nystagmus response itself is not a necessary condition for these signs of adaptation, and the former point is important because the response decline appears to be not just another sign of attention habituation. This form of adaptation seems to be more prominent in lower animals than in man, but it is clearly present in man (58). Recently Goldberg and Fernandez (59) found that some first-order ampullar neurons in monkeys showed changes in response during and after prolonged stimulation, like those encountered in human nystagmus and sensation, whereas other neurons did not exhibit "adaptation effects." The normal semicircular canal response is bilateral and yields a differential input to the central nervous system. Goldberg and Fernandez found a return toward spontaneous firing levels in units whose initial response was decreased by the stimulus, as well as in units responding by increased firing rates. Whether or not such neural responses reflect a selective efferent suppression on some neurons or some kind of selective peripheral adaptation process, there is an analogous suppression of the nystagmus response, and an even greater suppression of the subjective sensations during prolonged constant stimulation.

Groen (60) has proposed that this kind of adaptation process is deficient in some men, and these individuals will constitute a chronically "motion sick" group. There is some evidence which supports this contention and if it is correct, then it should be possible to develop some reliable simple tests to select out such individuals. There is, however, some conflicting evidence (61), and it appears reasonably certain that simple sensory tests used alone will not be sufficient to detect all categories of individuals who will not readily adjust to unnatural motion environments.

Groen (60) also has proposed that during periodic stimulation, a neural copy of the sensory pattern develops so that balance is maintained more or less automatically, and he adduced convincing evidence in support of this idea. There is little question that something like this happens, but it is not at all established that the adaptation effects referred to in the previous section are necessarily a sign of this process or of individual differences in this capacity. However, if they are, then some very simple short quantitative tests will have far-reaching significance, and this is a matter of current research in Pensacola.

The most impressive evidence for Groen's "pattern copy" hypothesis comes from after-effects of prolonged exposure to periodic or other unnatural stimulation in which the subjects have initiated voluntary movements in a lighted structured visual field. Thus the coordination of visual, vestibular, and proprioceptive inputs during a voluntarily initiated task are part of the exposure history in active fighter pilots who showed suppressed cupulograms (62), sea voyagers who experienced a rolling countryside upon debarkation (60), and in man recovering from exposure on the Pensacola rotating room (63).

It is not intended to imply by these comments that some degree of pattern copy cannot develop in the absence of enforced visual, proprioceptive, and vestibular interaction. Indeed, Groen (personal communication) has found some experimental evidence suggestive of pattern copy after simple sinusoidal oscillation in the dark. Also, Kennedy (64) has shown impressive changes in phase relations during prolonged sinusoidal oscillation, especially when arousal was not maintained. However, it is of practical importance to find those conditions which maximize the development of pattern copy, control the way that vestibular and associated responses are altered, and influence the retention of altered responses.

A number of studies have indicated that acquisition of control over involuntary responses (15) is aided by pairing them with supporting responses already under voluntary control. Recent studies demonstrating that heart rate and other involuntary actions may be brought under a degree of voluntary control have heightened interest in this topic (19-21).

Vestibular nystagmus and vestibular sensations are not typically under voluntary control when these reactions are produced by passive rotation in a dark room. However, when the person has a visual task that requires voluntary visual suppression of nystagmus, then the repeated pairing of such a visual task with the vestibular stimulus eventually results in a habituation of vestibular nystagmus to that stimulus even in the dark. This is illustrated in Figure 1.

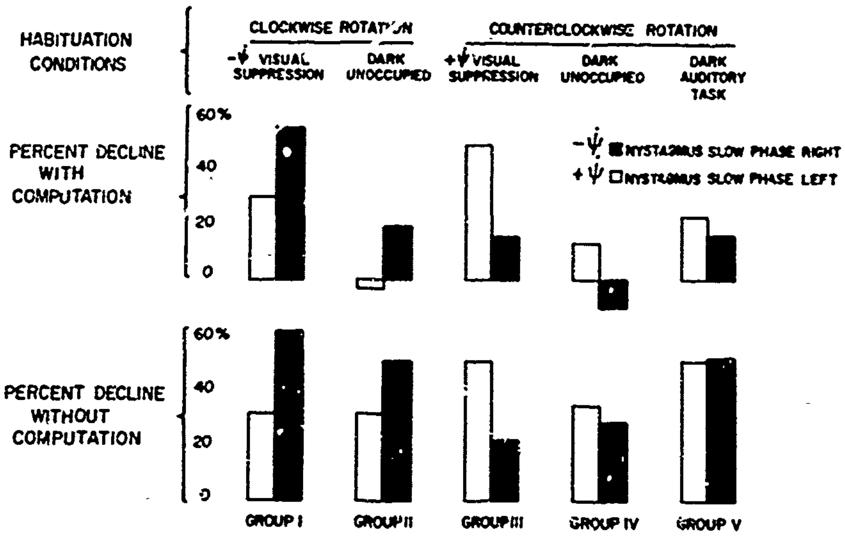

Figure 1. Nystagmus Per Cent Decline in Groups of Ten Men Tested in Darkness with and without Computational Arousal before and after Habituation Series of 80 one-minute Rotation Trials. During the habituation, postrotation nystagmus was visually suppressed in Groups I and III by presenting problems requiring visual control of eye movements. Suppressed was nystagmus right (-ψ) in Group I, nystagmus left (ψ) in Group III. Groups II, IV, and V were habituated in darkness, but Group V solved auditorily presented problems after each trial.

Figure 1 also shows that control groups "habituated" in darkness showed about the same nystagmus reduction as the visual suppression groups when both groups were tested without requirement for arithmetic computations in darkness. However, when the groups were again tested in darkness while doing mental arithmetic, then only the groups habituated with visual suppression of nystagmus showed a significant nystagmus habituation in darkness, and this was present only for the direction of nystagmus that had been visually suppressed. This directionally specific nystagmus habituation imposed by the repeated pairing of visual and vestibular stimuli in a particular way indicates that some sensory-motor retraining has taken place which carries over to the dark condition. This kind of nystagmus change seems to be different from nystagmus changes brought about by "arousal habituation" and from adaptation effects during prolonged single responses.

One of the most interesting experiments on this topic has been carried out by Gonshor et al. (65) who showed that prolonged sinusoidal oscillation did not produce nystagmus habituation to sinusoidal oscillation as long as mental arousal by arithmetic computations was required. However, when subjects wore right-left reversing prisms throughout the day and were tested from time to time by 2-minute periods of passive sinusoidal oscillation in darkness during mental computation, nystagmus was reduced, and there were marked changes in phase relations (almost 180 deg) between nystagmus reversal and chair reversal; i.e., the ocular response to vestibular signals was phase shifted to accomplish a functional coordination of the visual and vestibular inputs. Thus the normal coordination between visual, vestibular, and proprioceptive inputs was rearranged by active voluntary movement while the subjects wore right-left reversing lenses; evidence of this adaptative rearrangement was obtained from "involuntary" vestibular nystagmus recorded during passive angular oscillation in darkness with the subjects

doing arithmetic computations.

Arousal and focus of attention could [illegible] habituation process in several ways. First, arousal can reinstate nystagmus that has been reduced by attenti[illegible]on. It may also increase the amount of adaptive suppression if we assume that the suppression is proportional to [illegible] change in neural activity during the response (53, p. 90-91). In this connection, the difference between the dark auditory arousal group (Group V) and the dark unoccupied groups (Groups II and IV) in Figure 1 may be relevant. Focus of attention (66) or gating (cf. 13, p. 634f) may influence which aspect of the vestibular response is affected by pairing with a suppressing visual stimulus. For example, the visual task required of Groups I and III in Figure 1 required solution of visually presented mechanical-comprehension problems. There was little difference in sensation habituation (not shown in Figure 1) in thes subjects and those groups habituated in darkness even though there were differences in nystagmus suppression. This is in contrast to an early experiment in which subjects were urged to report cessation of sensation as soon as it occurred, and significant differences were found between groups habituated with visual suppression and those habituated in darkness (67). Sokolov (68) and Pribram (66) both emphasize the importance of cortical levels of awareness to model building and habituation.

C. Habituation to Complex Stimulus Environments

The experiment of Gonshor et al. (65) in which subjects wore right-left reversing prisms involved a more complex form of habituation than simple changes in response to rotation about an Earth-vertical axis. The active movement with visual feedback required central-nervous-system adjustment to new relations between visual, vestibular, and proprioceptive inputs in various planes of motion. This is one of a whole class of experiments involving what has been referred to as "geometric displacement" (9) or "sensory rearrangement" (cf. 13, 34). Typically, subjects have worn optical devices such as prisms, or mirrors, which displace, tilt, invert, or reverse the visual field. Quantitative performance measures have usually involved some kind of eye-hand coordination test or walking test during and after the period of sensory rearrangement. These studies have usually shown a considerable improvement in performance during the exposure period, impressive aftereffects when the distorted input was removed, pronounced individual differences in the initial effects and in rate of perceptual, performance, and emotional adjustment to distorted input. In general, Held's work has demonstrated that sensory-motor adjustments are more readily learned when the subjects made active (voluntary) movements during the sensory rearrangement (13, p. 607f, and Chapt. 4 in 34), although this is subject to some debate (cf. Chapts. 2 and 14 in 34). The work of Taub and Berman (Chapt. 11 in 34), however, strongly suggests that volition contributes to the learning process, as indicated by the demonstration of learning after deafferentation of limbs. Something like reafference seems to influence immediate perception and also learning.

It is perhaps significant that there is considerable evidence for phylogenetic differences in the rearrangement experiments. Taub (Chapt. 6 in 34) indicates that below ...."the class mammalia, there is no indication of ability to compensate behaviorally either for visual inversion or for reversal of direction of action exerted by limb antagonists. The higher mammals, on the other hand, are able to compensate for both types of rearrangement."

It is quite important to note that the kinds of rearrangements purposely produced in these experiments with visual apparatus of various types are quite similar to the kinds of rearrangements that are introduced by some forms of flight simulators. The adjustment probably involves a recalibration of several body systems, including several motor systems, several sensory systems, and complex sensory-motor reactions during intentional as well as passive movements.

A recent series of investigations, originated by Graybiel (69), has been regarded as primarily of interest in vestibular research, but this experimental situation is really a subtle and important form of rearrangement experiment (39,63). When a person is free to move around in an enclosed, lighted, slowly rotating room, more than a simple rearrangement of visual and vestibular inputs is involved. Walking along a straight line on the floor of the room is really walking along a curved path relative to the Earth. This curvature is sensed by the limb proprioceptor system while the visual system "reports" linear motion. When the person stands still at the periphery of the room, the room on the other side looks "uphill" because the resultant force (resolution of gravity and the force from the centripetal acceleration) is tilted relative to gravity. Since the angle of the resultant force relative to gravity diminishes toward center, the perceived tilt varies with the person's position in the room. The most immediately disturbing effect is produced by head tilts about any axis that is approximately at right angles to the axis of room rotation. During the head motion the axis of the resultant canal stimulus differs considerably from the axis of intended head motion and from the axis of change in position signaled by the otoliths and neck. Upon completion of the head motion, there is a residual canal signal (reafference), indicating motion at right angles to the intended plane (efference copy) of motion, and this is also at variance with concurrent otolith and proprioceptive information that indicates the position change has stopped. Thus, in addition to the required visual-vestibular-proprioceptive rearrangement, there is an intralabyrinthine rearrangement since the two labyrinthine subsystems which normally function synergistically now provide information that would require completely different sets of compensatory movements.

Individuals deprived of labyrinthine function experience all of the other visual proprioceptive rearrangement problems of living in the rotating room and show perrotational and postrotational changes in motor coordination without being troubled by nausea or motion sickness (70). From this and other related considerations, Money (35) has concluded that a functional labyrinth is necessary for the occurrence of motion sickness, and Reason (71) has concluded that a spatial sensory rearrangement in which the vestibular system is always one party in the conflict is necessary for motion sickness. At any rate, as with the rearrangement experiments in which vision was distorted, the results of the rotating room experiments showed that people could "adjust" to this kind of environment even during fairly high rates of rotation. There were, as with the other rearrangement experiments, considerable individual differences in initial reactions and in rates of adjustment irrespective of whether they were measured by reflex activity, such as nystagmus, emotional reactions (neurovegetative signs), performance measures, or subjective reports of motion sensations.

Nystagmus and the sensations of motion are valuable signs of the kind of neurophysiological recoding which can take place during exposure to this kind of situation, as shown in Figure 2.

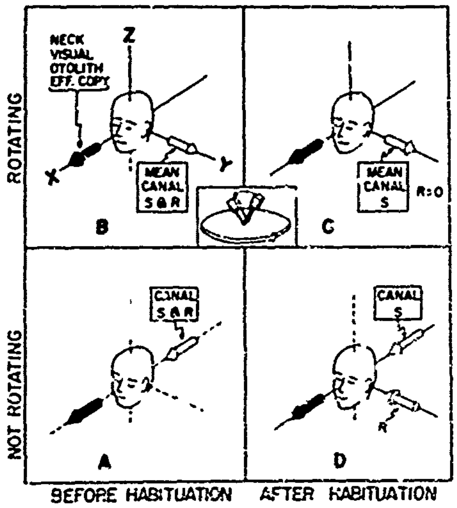

Figure 2. Canal Stimulus (S) and Response (R) during Head Tilts before and after Habituation in Normal and Rotation Environments.
In a natural environment, head rotation about the x-axis from a left lateral position to a right lateral position produces a counterrolling eye movement about the x-axis and a sensation of x-axis head tilt (A). As the head movement stops, the sensation stops and the eye velocity stops. In the enclosed rotating environment, however, the same head movement about the x-axis produces eye movement and rotary sensation about a changing axis intermediate between the x-, y-, and z-axes and an after-response of almost pure y-axis nystagmus which in darkness requires 10 or 15 seconds to dissipate (B). During habituation, with active movement and visual suppression, these discordant canal responses diminish (C). Shortly thereafter, testing in darkness with head movements in the natural nonrotating environment reveals eye movements and sensations opposite in direction to those which had occurred in the rotation condition; this represents a new sensory-motor relationship in which a particular sensory input in a natural environment produces a sensation and nystagmus in a plane which differs by almost 90 deg (D) from the plane of the original response in the natural environment.

At this time, a head movement while the subject is standing unsupported and with eyes closed causes him to fall in a direction compensatory to the recoded message. A recoding or reorganization of sensory-motor and sensory-perceptual relations has occurred (cf. 63).

These rotating room studies have served to emphasize that change in vestibular nystagmus, though an objectively measurable reflex, is only one sign of habituation and that it is not always correlated with similar changes in other aspects of the over-all reaction to spatial sensory rearrangement. Nystagmus may decline while nausea increases, and after vomiting, the opposite sometimes occurs. A comparison of several experiments illustrates the subtle factors involved in these various changes. Reason and Diaz (71) carried out a study in which three groups of subjects made head movements in a rotating structure. One group was enclosed in the structure and had only internal visual reference (IVR); a second group had full view of the external Earth-fixed room and had external visual reference (EVR); and a third group was blindfolded. All three groups were required to give frequent ratings of motion sensations and of feelings of well-being. Under these circumstances, the IVR condition clearly provoked a greater decline of well-being and more severe symptoms of motion sickness than either of the other conditions. In regard to motion sickness, these results of Reason and Diaz appear to reverse earlier findings by Guedry (72), in which a group habituated to head movements under IVR conditions exhibited less sickness (and more nystagmus habituation) than a group habituated in darkness. However, in Guedry's study the IVR group was mentally occupied with visually-presented problems, whereas the dark group was mentally unoccupied. Several experiments, including recent work with the Brief Vestibular Disorientation Test, have demonstrated that signs like pallor, sweating, nausea and sickness are reduced by assigned mental tasks during exposure to provocative stimuli in darkness (73,74).

Thus, controlled mental activity can ameliorate motion-sickness symptoms, whereas visual-vestibular interplay can facilitate nystagmus habituation (72) or exacerbate motion sickness (10, p. 49, 38) or reduce motion sickness. In this connection the EVR group of Reason and Diaz (71) showed far less emotional disturbance than did the IVR group. The immediate amelioration of emotional disturbance of the EVR conditions can be easily demonstrated with the well-known Link trainer, slightly modified. During rotation at a fairly rapid rate (e.g., 20 rpm), head movements in the darkened interior will disturb most people. With the cockpit illuminated, the same head movements will again be highly disturbing. If, however, the cockpit is opened so that the external room is visible, the emotional effects of the head movements are strikingly reduced. The veridical visual information on motion relative to the external world melds the inertial messages from the canals and otoliths and the expected sensory feedback into more synergistic information concerning head motion relative to the fixed external frame of reference. For example, in darkness a right-lateral head tilt from upright position during clockwise rotation produces a climbing sensation and diagonal vertical nystagmus with slow phase down. The subject expects a sensation of right-lateral head tilt (efference copy) and gets something (reafference) entirely different. With the external view available, however, it is clear as soon as the head movement starts that the lateral head tilt relative to the body "causes" motion of the visual field in a diagonal downward direction relative to the head; moreover, the diagonal vestibular nystagmus with slow phase downward relative to the head is in a direction to aid visual acuity of this moving field. This is the condition under which pilots usually learn to fly, i.e., with good visual reference. It is a favorable condition because the mental occupation with the flight task affords some reduction in the emotional consequences of discordant spatial sensory data and also because the external visual reference can transform sensory discordance into more nearly concordant information. On the other hand, a person trained only under conditions of good visual reference may not be prepared for the emotional impact that can result from discordant spatial sensory data when external visual reference is either reduced, absent, or misleading. It is a simple inexpensive matter to demonstrate the influence of the presence or absence of external visual reference on the disturbing qualities of unnatural motion stimuli.

Habituation to unnatural motion environments involves changes of a number of different reaction systems, and the conditions of exposure, including interaction of the various sensory inputs and the task of the individual, influence not only the immediate perception, oculomotor reflex activity, and emotional reaction, but also the rates of habituation of these various components of the total reaction. It is proposed that the way in which various involuntary response components change is determined in part by association of these components with other components that are under more direct voluntary control (cf. 15) and that naturally suppress or facilitate the particular reaction. The most obvious example is the pairing of vestibular nystagmus with a visual task that requires voluntary control of the eyes. The plane (63,72), the magnitude (63,72), and the phase relations (65) of the oculomotor response can be changed in this way. A less obvious example is the emotional aspect of the reaction. This component, of course, can be ameliorated when it is possible to demonstrate that the exposure really is not dangerous (when, in fact, it is not) but it is also possible that demonstrations of the effect of purposeful pairing

of mental computations with mildly disturbing stimuli may prove helpful in bringing the emotional components under voluntary control. The person can be shown that mental distraction from the peculiar sensations reduces the disturbance they produce. Another way which may be effective is to pair voluntarily controlled respiration with the unnatural stimulus. The Coriolis "cross-coupling" stimulus produces gross changes in respiration in some people. Some individuals seem uninfluenced by this stimulus, but others hold the breath, while still others increase rate and depth of breathing. I have found myself doing the latter while experiencing such stimuli. At these times I experience immediate fear despite the fact that I intellectually believe myself to be in a safe condition. By consciously controlling respiration before, during, and after the stimulus, these immediate fear reactions seem considerably reduced. If this can be proven by future studies, it will be a nice tribute to the classic James-Lange theory of emotion, and it may be a highly practical bit of knowledge for instructing and habituating pilots in regard to a primary danger of disorientation stress; i e., the immediate fear or panic reactions.

In summary, it is clear that the habituation of practical interest to aviation medicine involves much more than changes in vestibular reactions <u>per se</u>. The various changes in vestibular reactions are, however, intimately involved with various sensory, cognitive, and emotional processes of habituation; in this context, an understanding of changes in vestibular reactions, which typically are not under conscious voluntary control, has far-reaching significance for aviation medicine. It is proposed that there are several mechanisms of vestibular habituation:

1. A short-term adaptive change whereby sustained change in level of vestibular sensory input initiates counterprocesses to return sensory inflow toward the initial level of activity (57,75). This process is presumed to operate irrespective of cognitive assessment of stimulus significance. It involves an inhibition or suppression of signals at various sites in the nervous system and may be dependent upon efferent suppression from higher levels, as Groen has suggested for the vestibular system (60) and as others have suggested for other systems (p. 104 in 53). That individual differences in decay of various responses to prolonged sensory stimuli may represent idiosyncratic differences in general cortical suppression has been reviewed by Reason (76).

2. An "attention habituation" whereby familiar stimuli are processed, classified as familiar and inconsequential, and thus no reaction is elicited. Incoming signals are categorized and compared with stored information with minimal conscious awareness. The perceived current situation leads to an expected range of inconsequential messages, and messages falling within this range do not elicit irrelevant vestibular reflex activity (except when there is extraneous mental arousal), and no perceptual awareness. Messages outside this range elicit reflex activity and perceptual awareness. Exposure to varied conditions of motion in various situations involves a continual updating of the significance of messages. This process is presumed to involve more complex systems than those involved in the short-term adaptive change. Its functional value is that attention and energies are not expended unnecessarily. However, heightened mental arousal can switch off this habituation and induce vestibular reflex action. In flight, this could contribute to undesirable tension at a time when fine sensory-motor coordination and quick-decision making are essential. The processes proposed are comparable to the alerting, focusing, model-forming proposed by Pribram (53, p. 87). Studies of the late components of cortical evoked potentials suggesting that they are related to the cognitive significance of sensory stimuli (22,37,53) also provide physiological evidence for this assumed process.

3. A pattern copy process whereby repeating sequences are copied to set up efficient immediate responses and also efficient rhythms of response to sequences of continuous movement. This usually involves the dropping out of physiologically inefficient actions, such as generalized muscle tension, and unnecessary cognitive attention to actions and reactions. This, therefore, involves an updating of signals which is part of the arousal and attention habituation process.

4. Under unusual conditions a rearrangement of sensory-perceptual and sensory-motor relations is demanded by the environmental conditions and the individual's task. Rearrangement is a learning process. It is facilitated by voluntary activity and the pairing of sensory inputs that elicit voluntarily controlled responses, which naturally suppress or facilitate responses not under voluntary control. Under such circumstances, the establishment of new sensory-motor and sensory-perceptual relations is facilitated.

5. Components of the processes involved in attention habituation are necessary (and those involved in short-term adaptation may be necessary) for this higher order (more complex) habituation. The lower order processes which effect either the reduction or reactivation of natural responses, permit rapid adjustment of behavior to novel sensory inputs. They also serve to prevent rapid development of sensory-motor rearrangements that would be maladaptive in most natural circumstances. Thus it is assumed that attention habituation and suppression may serve to prevent learning of rearrangements by preventing cortical levels of awareness, except when this additional stage of learning is demanded by the task and motion environment.

6. Visual, vestibular, and proprioceptive inputs relevant to orientation and motion that are mutually discordant or that involve mismatches between reafference and efference copy signify an emergency condition, which elicits emotional and anxiety reactions. Individual differences in the magnitude of these emotional reactions influence the rate of habituation by the various mechanisms proposed above.

V. RELEVANCE TO SELECTION, ASSIGNMENT, AND TRAINING IN AVIATION SPECIALTIES

In the preceding sections, evidence has been adduced for a speculative theory which proposes that emotional reactions are connected to positioning, movement, and the control of movement in various stages of development by natural conditioning. Conditioned emotional reactions to control of movement influence personality, motivation (drive), and cognitive development, including abilities with spatial relations Other factors that influence personality, including inherited characteristics, also influence the magnitude of emotional reactions to motion stimuli. The developmental stage in which unfavorable conditioning occurs influences later adaptability to different control tasks during exposure to unnatural motion. Sensory inputs relevant to orientation and motion that are mutually discordant or that involve mismatches between reafference and efference copy signify an emergency condition which elicits emotional and anxiety reactions. When these reactions are excessive, the integrative function of the limbic system may be temporarily disrupted. These excessive reactions can be detected by the Brief Vestibular Disorientation Test (BVDT) which produces effects and performance change suggestive of functions that have been ascribed to the limbic system (37). Excessive emotional reactivity to control of motion in flight, in addition to degrading fine motor control (2, p. 1116f), can interfere with detecting and remembering significant components of the stimulus, and learning new stimulus-response sequences that are necessary to free the higher mental processes for higher-order decision making (cf. 37, p. 126-127). Conditioning procedures can reduce the emotional reactivity to discordant motion

stimuli and also can suppress some of the sensory discordance. To some extent the feasibility of these procedures from a practical point of view depends upon the individual degree of emotional reactivity as well as upon the presence or absence of other abilities and experience that control behavioral effectiveness.

Implications for Selection and Assignment of Flight Personnel. From the theoretical position presented, it is not surprising that the BVDT (5,73) and other similar tests (6) have been found to be valid predictors of flight failures and attritions. Recently (73) an inverse relation has been found between BVDT reactivity scores and performance requiring both vigilance and short-term recall. This supports the idea that mental function important to flight tasks can be degraded by such reactions. It is also to be expected that some personality tests would correlate with the BVDT, and there have been recent findings of significant correlations (73), although crossvalidations must still be obtained This form of test may eventually prove useful in personality evaluation for a broader application.

The reaction to the cross-coupling effects of tilting the head during whole-body rotation is what is evaluated by the BVDT. In this stimulus situation it is primarily the semicircular canal reafference that is mismatched with otolith and proprioceptor signals and with efference copy. For this reason, evaluation of vestibular nystagmus produced by simple semicircular canal stimulation is a valuable adjunct to the BVDT. During such testing it is desirable to introduce stimuli and techniques that permit reliable assessment of the lower order adaptive suppression of prolonged reactions. If a lack of suppression here would detect the absence of necessary central regulatory processes which is one of several requisites for adapting to unnatural motion according to Groen (60), then this test would detect such a deficiency. It might prove valuable also to test the suppression of after-nystagmus and sensation by repositioning and by visual stimuli. Each of these tests should have diagnostic potential concerning basic requirements for higher order adaptation and, in combination, should be valuable for differential diagnosis as well as for use in personnel selection.

Correlations between BVDT scores, spatial relations scores, and other tests of flight aptitude are to be expected and have been found (73). However, various combinations of scores on various tests relating to flight success should be examined carefully for a number of reasons. Owing to differences between pilot and crew in regard to the immediate feedback and consequences of their control actions (cf. Section III above), it is not unlikely that a combination of traits optimal for one group will be less than optimal for the other. A person who has success in sports and other activities that reward voluntary control of highly coordinated motion may be a reasonably strong reactor on the BVDT. Early stages of developmental conditioning may have produced an emotional reactivity to passive motion. However, in a later developmental stage involving voluntary movement, rewards for voluntary control of motion may combine with the above-average emotional reactivity to yield a high motivation for voluntary control of movement. Seeking challenges in the voluntary control of motion could eventually lead to success in sports. Such a person might show a fairly strong BVDT reaction because the voluntary head movement produces a mismatch between efference copy and reafference, thereby challenging the voluntary control of behavior. However, the external visual reference in early stages of flight training, the individual's motivation, and the voluntary initiation of actions that control sensory feedback in the piloting task may be a favorable combination for conditioned suppression of the inefficient reactions; i.e., for the development of expectancies or models that cancel the discord. The same person might fail as a nonpilot flight officer whose functions would be important to the long-range mission and safety of the flight, but whose control actions would in no way control the immediate response of the aircraft and whose actions would be carried out without external visual reference. For such reasons, it appears likely that refinements of the BVDT, including performance testing during both active and passive motions, may provide additional predictive capability, including the potential for determining flight assignment. In this connection, recent BVDT performance test results have shown a stronger correlation to nonpilot flight officer criteria than those for pilot trainees (73).

Relation to Training Devices. Instruction on disorientation is important in aviation because anticipation of provocative conditions is an effective countermeasure. Instructional material should be simple and current because errors can challenge the creditability of all the material presented. Flight demonstrations are highly desirable; however, this section is primarily addressed to the use of training devices. It is important to make a distinction regarding the use of these devices as quick demonstrators, as trainers (including simulators) which "save" flight time, and as means of habituating or conditioning the individual. In regard to demonstrators, it is a simple and inexpensive matter to set up a device that will suffice for demonstrating both disorientation and some factors that reduce it. The cross-coupling effects of tilting the head during rotation; the sensation of no rotation during rotation and conversely of sensed rotation when stopped; and the perception of tilt (relative to the Earth) when in fact the tilt is relative to a resultant force vector can all be demonstrated with a very inexpensive device. The same device can serve to demonstrate how the expectation of rotation can lead to sensations of rotation under restricted visual conditions, and more important, how external visual reference can reduce disorienting effects. Because the magnitude of the disorientation can be controlled, it is entirely feasible to demonstrate clearly to any normal person that he can be disoriented, that inattention can produce disorientation under mild conditions, and that a major part of disorientation can be overcome.

With very little more apparatus expense, it can be demonstrated that flying by instruments during disorientation is not difficult (when emotional tensions are not involved), and it would cost only a little more in time to demonstrate that two or three social drinks can seriously impair normal ability to "fly by instruments" during this same disorienting stimulus. All of these things can be done without major equipment expense. In regard to trainers and flight simulators, with the device just mentioned, it would be possible to train a person to track one flight instrument and scan others during disorientation. Improvement in tracking ability could double as a selection measure. Whenever training is given in motion devices other than in an aircraft, however, the potential of undesirable transfer of training is present. Such devices, therefore, require careful consideration. This is especially true of simulators and simulated flight profiles involving a cockpit mock-up of the real aircraft. With multi-degree-of-freedom centrifuges, it is not uncommon to vary position of the man relative to the resultant of the gravity and the centripetal acceleration components in order to simulate a flight profile. This always introduces cross-coupling effects that are different from those which would be experienced in the actual flight. Here the degree of training and stated purpose of the training may be quite important. The simulator sometimes provides a more difficult flight control task that does the aircraft; under such circumstances, the simulator can show that the "flight job" can be done under difficult disorienting circumstances. However, an extended training program without clarification of probable differences in the

simulated and real flight conditions may lead to difficulties in flight, just as the absence of inertial feedback cues led to difficulties in experienced pilots with the visual motion simulators (10, p. 49). The current knowledge of perceptual and neuromuscular effects of variation in magnitude and direction of linear acceleration vectors combined with inertial torques of various magnitudes and direction, though advancing, is not yet to the point where predictions of reactions can be made with confidence. Because of its direct application both to the use of simulators and in predicting and describing reactions in flight, this remains an important area for additional research.

Habituation of Undesirable Reactions. In Section IV it has been indicated that many of the undesirable effects of sensory-motor discordance produced by unnatural motion can be decreased by various habituation procedures. There are several questions about the practical use of such procedures. First, there is the question of whether or not habituation will transfer from the conditioning procedure to the flight environment. This has been answered affirmatively but tentatively by Dobie (77). Still a question remains as to which is the most efficient procedure. Based on theory proposed herein, conditioning aimed at reduction of the emotional components of the total reaction would appear more desirable than reduction of the magnitude of nystagmus or sensation to some particular stimulus. However, simply learning that this kind of specific habituation is possible could serve to reduce emotional tensions in flight, which would then enhance favorable adaptation to the flight environment. Exposure to a variety of motion conditions, including both active and passive motion, would seem to be desirable on the basis of developing learning sets (cf. 12, p. 77f). This seems to be the procedure followed by Russian scientists in preparing airmen and spacemen for flights (78). However, let us speculate on a procedure for reducing reactions to unnatural motions. A device with several degrees-of-freedom can be used to closely control the magnitude of discordance introduced by a variety of motion stimuli. The occurrence of passive stimuli can be forewarned by a signal tone, and excessive physiological reactions can be signaled through other channels to the trainee and to the examiner. Methods of bringing physiological reactions under voluntary control, comparable to those in current use (19-21), should be included and explained to the trainee. Control of graded passive motion stimuli should be kept within tolerance limits, measured by the magnitude of subjective and physiological reactions. Active control of graded passive movements should also be provided, first with external visual reference to reduce discordance and later with limited internal visual reference. Under the latter condition, an instrument tracking task should be introduced to distract attention from disturbing sensation and to build confidence in visual-motor control during disorientation. In addition, some tasks involving voluntary head movements during passive motion should be introduced, first during EVR, and then during IVR condition. In time, the magnitude of stimuli should be increased and eventually the warning signals omitted. With such techniques it seems likely that a number of people could be trained to reduce emotional reactions and tensions caused by unnatural motion and to improve concentration on the central flight task.

A second practical question pertains to the cost of such conditioning. In its most elaborate form it would be expensive at the outset and would probably never be practical for routine use, especially with individuals who do not otherwise possess favorable indices of flight aptitude. Likewise, individuals with exceptional BVDT reactions or without some of the basic requisites for adaptation to motion may be poor prospects for such conditioning procedures. However, for those individuals who do appear to be otherwise favorable prospects, some form of additional training of this nature may be both feasible and valuable. Pilots, pilot candidates, and flight personnel who encounter difficulty in the course of training can probably be helped when they are highly motivated to fly and when they have the necessary basic skills for their jobs.

Flying is regarded as a challenge by most people. A large percentage of the tales we recount involve either something we think we have done particularly well or some hardship or danger we have survived. A degree of anxiety may be desirable in a flight candidate, especially when it is a sign of a conscientious person who is willing to pursue a challenging goal. Skilled athletes are sometimes sick before or after a record-setting performance. The problems of selection, placement, routine training, and special training are closely interrelated.

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Opinions or conclusions contained in this report are those of the author. They are not to be construed as necessarily reflecting the view or the endorsement of the Department of the Navy.

DISCUSSION

The discussion following this paper was concerned mainly with the use of disorientation training devices. Dr Guedry distinguished between the demonstration of disorientation and the use of simulator like devices which might be used to 'save' flight time. He regarded the brief demonstration of the false sensations which can be produced in simple devices, such as that to be described by Dr Collins, as highly desirable, though he was in agreement with the opinion of Group Captain Dobie that there was no substitute for flight experience. He took a more cautious attitude towards dynamic simulators which he considered might give rise to an undesirable transfer of training, especially if an extended training programme were to be carried out in such a simulator without the aviator having a clear understanding of the differences between simulated and real flight conditions.

The use of the Brief Vestibular Disorientation Test (BVDT) was also discussed. Dr Guedry explained that the BVDT assessed a broader dimension of individual differences than 'sensitivity to vestibular stimulation'. Failure and attrition in flying training which correllated with high reactivity on the BVDT could not be attributed simply to difficulty in coping with orientational problems in flight.

PRACTICAL TECHNIQUES FOR DISORIENTATION FAMILIARIZATION AND THE INFLUENCE OF VISUAL REFERENCES AND ALCOHOL ON DISORIENTATION-RELATED RESPONSES

by

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SUMMARY

Techniques and procedures for providing on-the-ground familiarization of aviation personnel with disorientation problems are spelled out in detail. The techniques have been used with notable success both at the Civil Aeromedical Institute and in the field. They are relatively inexpensive, effective both for participants and observers, and are readily accepted by flyers as pertinent to the aviation situation. The extent to which disorientation is affected by the type of visual information available to the pilot is examined under normal conditions and when alcohol is involved; ways of demonstrating the deleterious effects of alcohol are described.

A number of general aviation pilots in the United States are unaware of the potential hazards of disorientation or vertigo, and many feel that they are immune to these undesirable aspects of flying. The major basis for this lack of experience is not immunity but the fact that most U.S. general aviation pilots are "weekend pilots" (i.e., infrequent flyers who rarely fly under anything other than good VFR conditions). Contributing to the latter is the fact that the vast majority of U.S. private pilots (about 96 per cent in 1969)[1] do not have instrument ratings, and many who are so rated do not maintain instrument proficiency. Since disorientation and "pilot's vertigo" are most likely to occur under IFR conditions, there is considerable danger in the feeling of security that pilots may develop regarding their ability not to suffer disorientation--a feeling that may be reinforced as a result of each VFR flight in which disorientation does not occur. In addition to those general aviation accidents which can be attributed directly to spatial disorientation, this unfortunate conviction is a possible contributing cause in many of the NTSB fatal accident reports which indicate that the pilot "continued VFR flight into adverse weather conditions."

The purpose of this report is to explain our approach to familiarizing aviation personnel with the hazards of disorientation and to provide suggestions for use in other training programs. It is important to note that our methodology is not designed to train pilots so that they will be immune to disorientation problems (no one with a normal vestibular system is immune), but only to familiarize them with many of the unusual and false perceptions of vestibular origin which can occur in flight, and to impress upon them the importance of obtaining an instrument rating and of maintaining instrument proficiency.

OUR BASIC TECHNIQUES FOR DISORIENTATION FAMILIARIZATION

We place considerable emphasis on the interaction of the various sensory systems, particularly those of vision and the semicircular canals. Since the pilot almost invariably has some visual frame of reference (e.g., if nothing else, at least the cockpit interior), his inflight experience with disorientation will involve vision in some way. This is also one of the major reasons why the traditional demonstration in the Barany chair is frequently not as effective as it might be; the subject is either blindfolded or shuts his eyes, is rapidly whirled, and is asked to make a head movement. The resulting sensation (Coriolis illusion) is usually striking, but appears to have little relation to the problems that might be encountered by a pilot in flight.

The Apparatus

Our first approach to providing adequate disorientation demonstrations involved a simple modification of a rotating device.[6] Specifically (a) a partial enclosure (see Figure 1) was introduced around the upper part of a motor-driven rotating chair (a Stille-Werner RS-3 Rotation Device), and (b) a removable headrest (which could be rotated upward) was fabricated with adjustable angled side pieces to control the amount of lateral head movement. The enclosure comprised a simple light-weight metal frame of two pieces that could be bolted to the back of the headrest. The entire inside of the frame (and the facing of the headrest) was coated with luminous paint and then sprayed with clear enamel as a radiation safety precaution. Since the front-piece extended only halfway up the height of the frame, the rider had a "window" through which he could observe a set of three tiny lights which simulated an "approaching aircraft" (red and green "wing-tip" lights and a flashing red "rotating beacon"). The lights were imbedded in a small plastic frame which was attached to the end of a rod. The base of the rod was secured to the rider's footrest and extended upward a ' way from him at a slight angle. A power source for the lights was located behind the chair.

Familiarization Procedure

Prior to rotation, the pilot is instructed to keep his head and body very still during the demonstration until he is asked to do otherwise. An outline and depiction of the complete sequence of procedural events and the concomitant subjective reactions appear in Figure 2. In making lateral head movements (30°-45°), he is instructed to keep the back of his head against the headrest and simply to slide his head

Figure 1. Modifications of a rotating device to control head movements and to introduce an aviation-related visual environment. The rod extending upward from the foot rest terminates in a plastic panel which contains three tiny lights (a red and a green "wing-tip" light and a flashing red "beacon") simulating an approaching aircraft. (The chin rest depicted here is used for research rather than demonstration purposes.) The major section of a "cabin" has been bolted to the back of the headrest; its base is further supported by small metal extensions projecting outward from the arms of the chair. An "instrument panel" (not shown here) is bolted across the lower half of the front of the "cabin"; the upper half of the "cabin"-front then becomes a "window" for viewing the "approaching aircraft" (see also ref. 6). The interior of the "cabin" was coated with luminous paint.

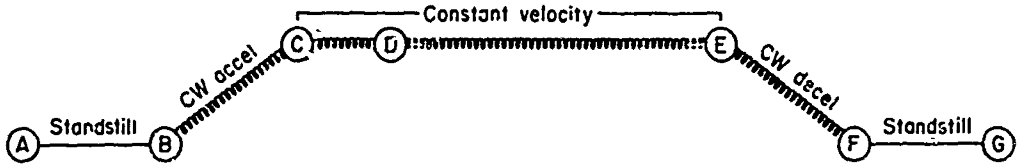
laterally until his cheek or temple touch the side-piece of the headrest. The head movement is to be made briskly and is to involve no body movement, i.e., the axis about which the head is to move is designated as around the "Adam's apple." The rider is told that he will be asked questions during the demonstration, which will be conducted in darkness. He is to describe his experience as accurately as he can.

Acceleration. Room lights are turned off and, since the room is light-proof, the pilot can see only the "approaching aircraft," framed through his "window," and the dimly lit interior of his "cabin": nothing else in the room is visible to him. After a few seconds, observers in the room can see the pilot dimly outlined against the luminous "cabin."

The pilot is asked to report the onset of his experience of motion and his direction of turn. A smooth clockwise acceleration of $5^{o}/sec^{2}$ for 18 seconds is then applied. During the acceleration period, the pilot is asked if his speed is changing at all. He, of course, replies that his turning speed to the right is increasing. He is then requested to indicate any further change in direction or in speed.

Constant Velocity. After the 18-second acceleration period, a constant turning velocity (15 rpm) is maintained. A few seconds after reaching constant velocity the pilot reports a slowing of his turning rate (if he does not report spontaneously, he is asked about it). Within another 5-20 seconds, he indicates that he no longer feels turning, i.e., that he is motionless. Shortly after this, some riders report a slight turning sensation in the opposite direction (a secondary sensation). This apparent motion to the left is a normal experience and, when the pilot spontaneously notes it, a strong impression is usually made on the observers. (The secondary sensation is considerably weaker than that experienced during acceleration and, in most cases, does not last longer than a few (10-15) seconds; in other cases, it may be quite persistent and last for well over 30 seconds.)

Some individuals fail to report that their initial turning sensation ever ends following the acceleration; all report a clear slowing down of the turning experience, but some will maintain that they continue to feel very slow movement to the right. (Note: This perception is probably unrelated to sensing the actual turn; these same individuals often report similar prolonged turning experience while actually stopped following deceleration.) In any event, after the first 30 seconds of constant velocity, the vestibular system has returned from a stimulated condition to sufficiently near its normal "at rest" state, to allow head movements to be introduced. In order to maximize the "Coriolis vestibular effects" produced by these head movements, it is important to allow sufficient time between them, as well as between the end of the acceleration and the start of the head movement. Note that the direction of the illusory experiences (e.g., "pitching up") specified below are for CW rotation; the directions are reversed during CCW rotation.



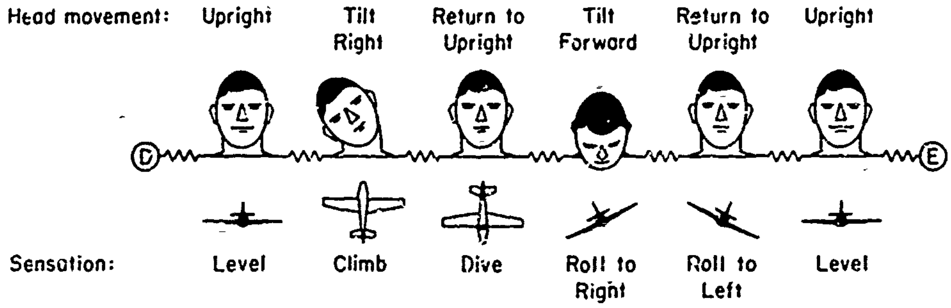
(A)→(B) Rotator at standstill.

(B)→(C) CW acceleration (5°/sec² for 18 sec).
Subject detects start of turning, direction of turn (to the right), and increasing velocity.

(C)→(E) Period of constant velocity at 15 rpm.

(C)→(D) Subject perceives velocity of right turn diminishing and, finally, all turning sensations cease.

(D)→(E) Subject makes head movements upon given signals.



(E)→(F) CW deceleration (5°/sec² for 18 sec).
Subject detects start of turning, direction of turn (to the left), and increasing velocity.

(F)→(G) Rotator at standstill.
Subject perceives velocity of left turn diminishing and, finally, all turning sensations cease.

Figure 2. Outline of the procedure for the CAMI disorientation demonstration. The entire procedure is conducted with the subject able to see only the "cabin" which surrounds him and the "approaching aircraft." Note that: (1) The sensations are reversed if CCW rotation is used; (2) returning the head to upright from a tilt to the right is equivalent to tilting the head to the left; (3) at least 30 seconds should be allowed between head movements; (4) the sensation experienced as a result of deceleration is directionally opposite that resulting from the acceleration and is perceived as a speeding-up rather than a slowing down.

Head Movements. The pilot is reminded about how to make the head movement and is asked to tilt his head to the right at the count of "three" (and to hold it there), and then to report what he experiences. The count is made and the subject tilts his head. The sensation is one of pitching up (sometimes up and to the right). The pilot is asked how many degrees "up" (between 20°-60° in most cases), and whether he "saw" the whole "cabin" pitch up with him and the "approaching aircraft" climb with him. It is important to note that this Coriolis reaction is not a simple feeling of tilt; the rider experiences a change in attitude (pitching up, for example) and an acceleration in that direction. Moreover, he not only "feels" a body motion, but his visual information, the "cockpit," and the "approaching aircraft" all change attitude in a corresponding manner. Some pilots also report sensations of pulling positive "G."

The sensation of pitching up and climbing has a sudden onset and then gradually decays, i.e., the pilot's apparent rate of climb decreases and he gradually returns to a "straight and level" condition. The amount of time required for this return can vary considerably among individuals but in any event, after 60 seconds (but no less than 30 seconds, even if the pilot indicates "straight and level" earlier) a signal for the return-to-upright head movement (this is equivalent to a left tilt of the head from an upright position) is given. The rider is usually warned that the sensation accompanying this head movement is likely to be somewhat stronger than that resulting from his tilt to the right (for certain physical and/or psychological reasons, it almost invariably is).

The signal is given and the pilot briskly moves his head to upright from its tilted position; his sensation is one of diving (sometimes down and to the right). Again he is asked how many degrees of "dive" he experienced (between 30°-90° in most cases) and whether the "cabin" and the approaching aircraft "dove" with him. This return-to-upright head movement occasionally produces sensations similar to negative "G" in experienced pilots. (Again, it should be noted that the experience is not one of simple

tilt forward, but of accelerating downward, and the "cabin" appears visually to be displaced and "diving" in that same direction.)

After 30-60 seconds elapse following the head movement, nodding motions are introduced. Here, the rider is instructed to look toward the floor or at his lap (as though he were seeking a dropped pencil) by simply dropping his chin toward his chest (i.e., by moving only his head). As with the other head movements, he is to hold his head in that anteverted position until signalled to return it to upright. The questions and timing are similar to those presented above for lateral tilts but, in this case, the pilot perceives roll of his aircraft to the right as a result of the forward movement of his head, and roll to the left upon returning his head to upright. It is sometimes necessary to clarify a rider's description of these experiences; some report a "turning" to the right or left, but, if questioned, they indicate that it is not a sensation in the yaw plane, but rather in the roll plane, i.e., as though about a barbecue spit.

(Note that the head movement should be straight forward and back, not at an angle, just as the lateral tilts should not involve twisting of the head. This recommended approach orients the semicircular canals in such a way that, for the most part, the sensations and visual impressions are relatively pure rolls and (vertical) climbs and dives. Subjects who move their heads differently have sensations which tend to be more complex, e.g., spiraling down and to the right, and therefore less simple for them to describe and more difficult for the instructor to predict with accuracy.)

Sensations generated by the last (return-to-upright) head movement are allowed to dissipate for the usual 30-60 second period. At the end of this time, the vast majority of riders perceive themselves as "straight and level" and still experience no turning sensation.

Deceleration. Prior to initiating the deceleration, the pilot is told that he is turning to the right (although he is not experiencing that turn) and will very soon be slowed down in that same direction, and brought to a complete stop. (This gives the pilot intellectual information about what will transpire.) However, he is to report when he feels motion, in which direction he perceives his turn, and is to give a running account of his experiences (i.e., to indicate when he is going faster, when he begins to slow down, and when he feels that he is stopped).

A smooth deceleration of $5^{\circ}/sec^2$ for 18 seconds is then applied. If the pilot neglects to indicate that he detects motion, he is asked; he is then asked the direction and whether or not he is turning at a faster or at a slower rate (his experience is that of turning faster and faster to the left, although he is actually slowing down in a right-hand turn, and he reports maximum turning velocity at, or very shortly after, reaching a complete stop). He then experiences a gradual slowing down and, after 5-20 seconds at a complete standstill, finally feels stopped. Room lights are then turned on and the demonstration is terminated.

Some Cautions

Too many head movements and higher turning velocities can cause the rider considerable discomfort and can lead to motion sickness; hence, the four movements noted above, at the turning rate specified, are usually sufficient to provide an adequate appreciation of disorientation problems. It is worthwhile to inquire of the pilot following the first or second movement whether or not he feels comfortable. A very few individuals (considerably less than 10 per cent) may experience early symptoms of motion sickness ("stomach awareness," sweating, coldness, very slight headache, etc.). If riders report discomfort, or if they indicate that the demonstration should be discontinued, they should be asked to keep their heads very still (even if in a tilted position) and should not be requested to make additional head movements; the rotation device should then be brought to a gentle stop. The rider's head should remain motionless for an additional 30 seconds after the device is stopped.

There are no formal data which indicate that pilots might be "sensitized" to experience disorientation, discomfort, or motion sickness in flight following a demonstration such as that outlined above. However, too many head movements during rotation (or, in some few individuals, the four movements described above) may produce a mild feeling of unease that might last for several hours. As a general rule, therefore, it is advisable for riders who feel no ill effects following the familiarization experience to abstain from flying for at least one hour; where possible, the demonstration might best be given on a day when the pilot is not going to fly at all. In any event, if a rider suffers discomfort or any stage of motion sickness during the familiarization (this is unlikely), he might best not fly at all that day.

There is a relation between the intensity of the sensations occasioned by the head tilts and the amount and speed of the movements. Thus, a very slow, cautious, head tilt of just a few degrees will elicit a relatively weak sensation whereas a head tilt of average speed through a greater arc will produce a much stronger response. Adequate disorientation experiences can be accomplished with tilts of 30°-45° when the head movements are made briskly.

It is important to note that experiences of turning and Coriolis sensations are both markedly affected by the type of visual information available. For example, if the walls of the room are visible during rotation, that visual information will change the character of the Coriolis sensation - the cockpit will not appear to pitch or roll and the vestibular sensations will be characterized by discomfort rather than by displacement and acceleration. In a sense, the vestibular information is modified and made to agree with the visual data (when the latter concerns objects fixed relative to the earth).

Advantages

The apparatus and procedures noted above provide the pilot with a disorientation familiarization experience that is considerably more meaningful than the usual Barany chair demonstration. The pilot has an opportunity to receive correct information from his motion-detecting system (during acceleration) and then can experience the failure of the system to provide accurate information during the remaining phases of the demonstration. The Coriolis effects are perceived in a more appropriate perspective when the head

movements are made within the lighted "cabin" and the power of this form of disorientation is better appreciated when the pilot not only "feels" a false change of attitude and acceleration, but also "sees" it occurring. The interaction between the visual and vestibular systems and the manner in which the visual information is made to agree with the vestibular sensations (when the visual objects are not fixed relative to the earth) is a very significant feature of this type of familiarization. All of these sensations are, of course, referred back to the lecture material so that the pilot will understand what has happened and why.

The fact that the device does not tilt or move in any plane other than yaw seems to be an advantage. It appears to intensify the impression made on the pilot when he sees that the device "only turns," although, as a rider, he experienced clear pitching and rolling sensations.

When done as described, i.e., in a light-proof room with the pilot reporting his experiences, responding to questions, and visible, the demonstration is not only effective for the rider, but also holds the interest of spectators while providing them with a learning experience. A most desirable situation is to provide at least two of the group with the familiarization experience; this procedure allows the initial pilot to see exactly what the stimulus conditions were, permits an interchange between the two (or more) riders regarding their experiences, and frequently provides the spectators with some notion of the individual differences in disorientation experiences (e.g., a 45° "dive" vs. a 90° "dive") as well as differences among subjects in their reaction to the Coriolis effects (some subjects, for example, will become extremely excited, others will simply appear to tense up, while others enjoy it). Almost every pilot who has ridden in the device has indicated that everyone who flies ought to have this experience.[e.g.,3,4]

Figure 3. The CAMI Disorientation Device. The chair from the basic Stille-Werner RS-3 Rotator (see Figure 1) was removed and was replaced by a relatively light-weight "cockpit" fabricated by the CAMI Technical Staff. The canopy is made of molded, clear plexiglass. A small light source mounted in the instrument panel is directed at the subject and, with the room in total darkness, permits observers to see the subject but the latter can see only the interior of the "cockpit" and the lights of the "approaching aircraft" (mounted on the "fuselage"). The headrest depicted here is padded, has fixed side pieces, and can be adjusted vertically.

<u>A Modification of our Apparatus</u>. For purposes primarily related to research, the basic Stille-Werner Rotation Device was modified by the CAMI Technical Staff by removing the standard chair and installing a cockpit seat and a lightweight "cockpit" with a door and plastic canopy which totally encloses the seated pilot (see Figure 3). A light source, located in the "instrument panel," serves to light dimly the interior of the "cockpit"; the rider can then be viewed by spectators in a totally dark room, but cannot himself see them. An "approaching aircraft" (the triad of red and green lights) was installed in the center of a small device on the fuselage which the pilot can see dimly through the plastic canopy (see Figure 4). The functioning of the apparatus so modified is, of course, not different from our first model (although the aviation-orientation of our demonstration is improved), and the procedures for disorientation familiarization detailed above are the same with one exception: either an inter-com is required, or the canopy must be raised an inch or two to permit communication between the rider and the instructor.

OTHER APPROACHES TO DISORIENTATION FAMILIARIZATION

The Vertigon

During a visit to CAMI, engineers (and pilots) from Flight Products, Incorporated (Moonachie, New Jersey) were given the CAMI disorientation demonstration and became convinced that the experience could be

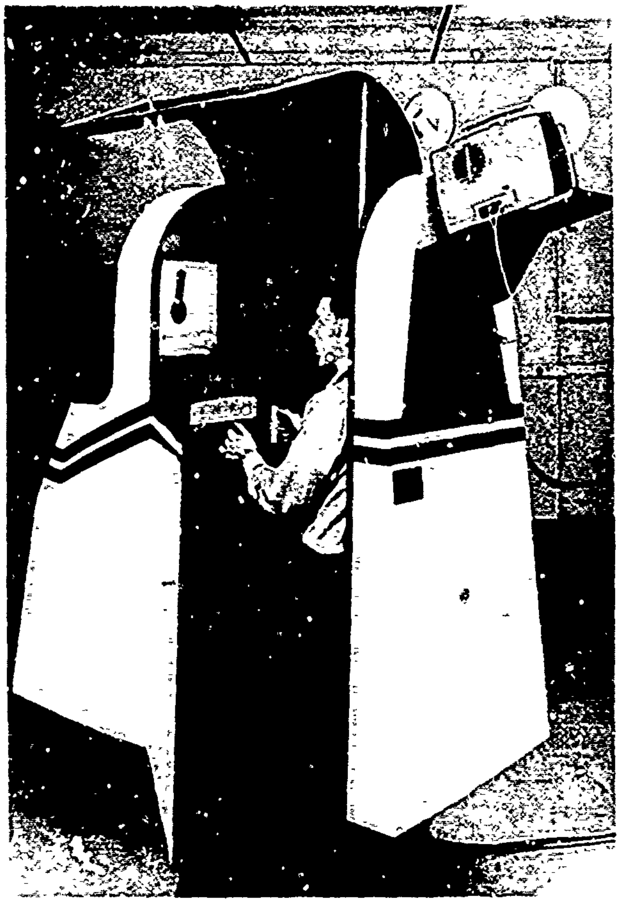


Figure 4. The Vertigon. The subject is totally enclosed in this rotating device and a sound movie depicting a flight from engine warm-up through a landing approach is projected on the "windshield." The control system for the Vertigon is simple, compact, and easy to operate

of benefit to all pilots. They agreed to build an instrument to be used specifically as a familiarization tool and were provided with basic specifications and timing procedures.

The Vertigon (see Figure 4) totally encloses the pilot in a one-place "cockpit" and provides reasonably smooth angular accelerations and decelerations. Sound movies projected on the windshield depict a flight from engine start through taxi, take-off, climb, and bank into clouds (where the head movements occur); following the period of head movements while "flying IFR," the plane breaks out of the clouds and begins a landing approach. The sound portion of the film gives an introduction to the problem of vertigo, indicates the possible thought processes of a pilot choosing to fly through clouds, adds realism to the head movements by having the pilot make some of them by performing tasks (such as reaching for a pencil and writing, on a pad in his lap, a simulated air traffic clearance, then returning the pencil), emphasizes how powerful the illusory effects are (while assuring the rider that he is still straight and level), and indicates that only the instruments can provide the pilot with correct information. The sound track concludes by encouraging the pilot to earn an instrument rating and to maintain instrument proficiency. The entire "flight" takes only four minutes. A closed-circuit TV system can also be installed so that observers can watch the facial expressions and head movements of the subject.

The Vertigon has been notably successful as a familiarization technique. Riders are impressed with the illusions and, as with the CAMI Disorientation Device, accept the procedural conditions as pertinent to the aviation environment. The importance of "seeing" the instrument panel, "windshield," and "cabin" surroundings pitch or roll in agreement with the vestibularly induced sensations cannot be over-emphasized.

The Vertigon has several advantages. It is durable and requires exceptionally little maintenance. The entire run can be programmed (there is a switch for manual or program control) so that minimal skill is needed to operate the device. It moves only in the yaw plane, requires very little space (about 6 feet by 6 feet) and can be used in a lighted room. Its acceleration characteristics and the smoothness of its start and stop are more than adequate for a good demonstration. It can also be modified to introduce other tasks, program meter deflections, require movements of the control wheel, etc. The film and sound track, of course, can also be modified as desired.

Modified Link Trainer

Based on their CAMI experiences, several visitors have modified their own equipment to provide an approach to disorientation familiarization similar to that of CAMI. A good example is the modified Link trainer (Figure 5) used by a Colorado, U.S.A., flying school. The device is essentially quite like the Vertigon. The trainer was stripped down except for the pedestal and cockpit box and modified so that only vertical-axis (yaw) movement was possible. The base of the trainer was fitted with a pulley and belt drive connected to a geared-down electric motor. A motor mount was fabricated and bolted to the base of the simulator and a pulley size was selected to drive the device at 16 rpm. Existing wiring was used to provide power (1) to the motor through a switch controlled from the cockpit box, (2) to separate plugs for a movie projector and a tape deck, each with a separate switch, (3) to warning lights connected to

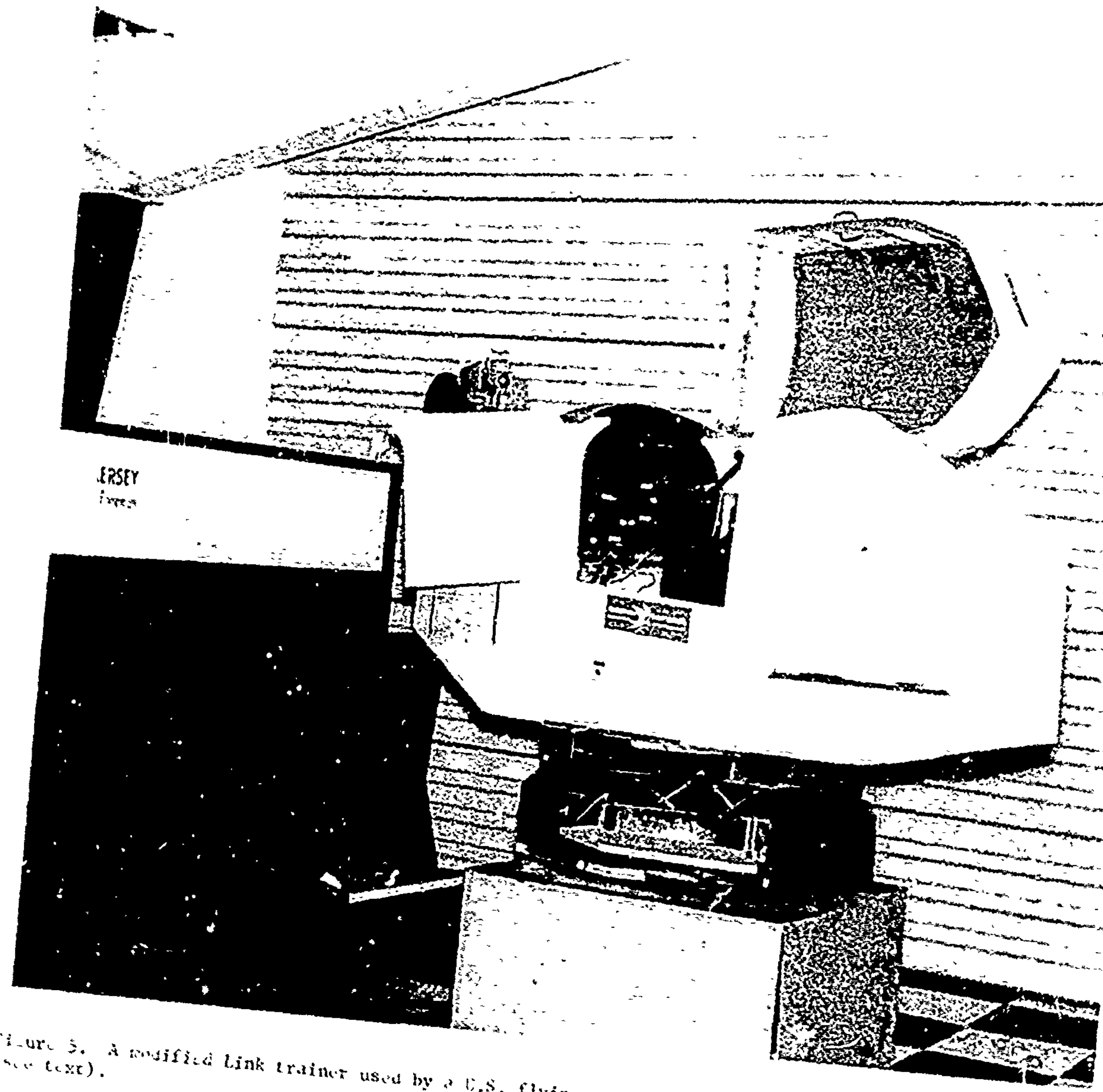


Figure 5. A modified Link trainer used by a U.S. flying school to provide disorientation familiarization (see text).

ric switches on the control quadrant which are activated if the rider attempts "corrective action" during the demonstration, and (4) to a single cockpit light and switch (not often used since ample light from [illegible] illumination filters through the translucent covering on the canopy). A platform was attached to the front of the trainer to support a rear-projection system which uses the front panel of the translucent canopy for a screen. A tape deck was provided in the front compartment, just forward of the existing rudder pedals, for narration. The rider is provided with a pad and pencil to accomplish workload assigned by means of the narration.

Converted Chairs

All of the devices described above are particularly effective in safely, but dramatically and personally, familiarizing the individual pilot with disorientation experiences and in providing a meaningful adjunct to instructional material. The devices can also be used independently [illegible] lecture-type background [illegible] not required. The Vertigon, for example, has been a highly successful familiarization tool at air shows with no more than the four-minute narrative which accompanies the motion picture. However, none of the devices so far described is truly portable and none is appropriate for some types of classroom demonstrations. (For example, if it is desired to show the nystagmus produced by angular stimulation (i.e., the pattern of slow drifts of the eyes away from their center position, alternating with fast ocular [illegible] back toward center), a different approach must be used.) In such cases, modified Barany-chair techniques are frequently instructive.

In expanding the CAMI disorientation training program, padded kitchen stools were converted to orientation familiarization devices by the CAMI Technical Staff (see Figure 6). These relatively inexpensive chairs were lowered to improve balance characteristics, a more substantial bearing system was installed, and a footrest, a "control stick," and a seat belt were added.

In conjunction with the stool, a special pair of goggles is frequently used. These were developed in the CAMI [illegible] Education Branch[5] to permit rotation of the pilot in a lighted room and to provide him with a visual [illegible] that was not fixed relative to the earth. A blue filter was substituted

Figure 6. The converted kitchen stool and goggles used by the FAA in disorientation familiarization for U.S. private pilots.

for the usual lens in a pair of welder's goggles, and a lightweight rectangular extension was secured to the frames. Openings for two battery-operated pen-light bulbs were made in the sides toward the front of the rectangular attachment. The interior of the attachment was highly polished metal which produces multi-reflections when the bulbs are lighted. Additional padding was introduced around the face-mask to prevent outside light leaks. The goggles provide several advantages: (1) room lights can be left on; (2) some visual effects can be demonstrated to the pilot; (3) they can be used with any rotating device, (4) they permit freedom of head movement. Disadvantages include: (1) some visual rivalry effects since the bulbs are directly opposite the pupils of the eyes; (2) Coriolis illusions are attenuated in comparison with a "cockpit"-type surround; (3) the visual field viewed through the goggles does not stay fixed (as an instrument panel or a landing strip would) when the pilot makes a head movement, i.e., when the pilot tilts his head, he tilts his visual field at the same time, regardless of whether or not he is rotating. One of the convincing features of the CAMI Disorientation Device, the Vertigon, and the modified Link trainer is the fact that illusory motion of the instrument panel occurs in the absence of physical movement of that panel.

The modified stools are reasonably effective. They are highly portable and inexpensive. For example, they can be easily broken down into three sections, quickly packed in a carton, and carried by hand. The base and the bearing system of this chair are of sufficient quality to insure safety, close tolerance, and minimal friction; thus, a simple manual push of the chair can set it and a student in motion for a minute or more of smooth, non-wobbling rotation. However, if not used carefully, the stools may present a safety problem under some conditions. The procedures used with the chairs are outlined below.[5] Note that each of the five demonstrations described involves a different student.

PROCEDURAL STEPS IN CLASSROOM DEMONSTRATION

First Demonstration

1. Explain to the student-demonstrator and the class how rotation of the Barany chair relates to aircraft turning.

2. Have the student indicate, by pointing with his thumbs or a joy stick, his position or the direction of the sensation he is experiencing. Caution him not to correct for illusions.

3. Place a hood (or goggles) over the student's eyes and have him sit erect. Rotate the chair to the right. Rotate the chair so that the seat will turn for at least one minute without additional pushing.

4. The student should first experience a sensation of rotating to the right, then almost a halt in rotation; as the chair slows down, he should experience a sensation of rotating to the left, and finally he will report stopping.

Second Demonstration

1. Rotate the student to the right with eyes closed and with no hood.

2. As soon as the student feels no sensation of rotation (or in about 20 seconds), stop the chair abruptly.

3. Stop the student in front of the class and have him read from material on an appropriate chart or sign.

4. Have the class focus its attention on the student's eyes.

5. The student's eyes should sweep or click to the left and right, thus demonstrating nystagmus.

Third Demonstration

1. Have the student don a hood.

2. Rotate the student until he no longer experiences turning.

3. Have the student tilt his head to the right while rotating.

4. He should experience an illusion of a climb to the right.

Fourth Demonstration

1. Using a hood, rotate the student to the right with his head tilted to the right.

2. Continue rotation until no sensation of turning is reported; then have the student return his head to the upright position.

3. The student should experience an illusion of diving.

4. Caution! The student may have a violent reaction to this stimulus.

Fifth Demonstration

1. Again using a hood, have the student look down at the floor or at his lap belt.

2. Rotate him to the right with his head tilted downward.

3. Continue rotation until no sensation of turning is reported; then have the student return his head to upright.

4. The student should experience an illusion of tumbling or spiraling.

5. Caution! A strong sensation of falling from the chair may be experienced.

Additional Techniques

The approaches noted above are not the only ones available. For example, the Spatial Orientation Trainer (SOT) at Brooks AFB, Texas, is a highly sophisticated device which has four degrees of freedom of movement; totally encloses the rider in a cockpit that moves on rubber wheels around a circular track 10 feet in diameter; and permits the pilot to control the attitude of the cockpit (at the discretion of the console operator) by stick, rudder, and throttle. The device can be rotated about its own axis (30 rpm) or around the track, can be pitched $\pm 30^{\circ}$ from the horizontal, and can be rolled $\pm 90^{\circ}$ from the vertical. A preliminary evaluation of the device using students from the Air Force Undergraduate Training Program indicated its usefulness and acceptability to the students in augmenting the regular flight training program.[6]

Still other techniques exist; however, the purpose of the present report was simply to provide suggestions and procedures for inexpensive but meaningful disorientation familiarization based on the enthusiastic responses of general aviation pilots who have experienced the CAMI approach, and to encourage pilots to obt... instrument ratings.

ALCOHOL AND DISORIENTATION

As a final area of consideration, the role which alcohol may play in disorientation can be demonstrated with any of the devices described above. In general, alcohol depresses the responses from stimulation of the semicircular canals. Thus, when tested in darkness, both nystagmus and subjective sensations of turning, as well as sensations produced by Coriolis stimulation, are reduced by alcohol.[7,8] However, alcohol also depresses the functioning of the visual fixation mechanism, such that the visual system becomes markedly less able to inhibit vestibular responses when alcohol is present.[7,8] Thus, under the latter condition, vertigo and blurred vision are noticeably present following an angular deceleration in the presence of visual fixation objects. This phenomenon is readily demonstrated by rotating subjects in darkness (or with their eyes closed) and bringing them to a sudden stop as the room lights are turned on (or as their eyes are opened). In the absence of alcohol, visual fixation on some object in the room will quickly inhibit both the turning sensation and the nystagmic eye movements. However, one hour after drinking (about 1 1/2-2cc of 100-proof liquor per kg of body weight, or about 3/4-1 ounce of 100-proof liquor per 33 pounds of body weight), if the same procedure is applied, visual fixation following the

sudden stop will be ineffective in preventing blurred vision, and vertigious sensations will be experienced for several seconds.

As might be anticipated from the above, alcohol will affect performance on at least some types of tasks during angular acceleration, although performance might be relatively unaffected in the absence of motion. Thus, for example, the ability to track a moving target by means of a stick control (eye-hand coordination) may not be impaired noticeably by alcohol when the subject is in a static (stationary) environment, but may be significantly depressed in a dynamic (angular acceleration) situation as a result of blurred vision.[9,10] Statistically significant increases in tracking error have been obtained during angular acceleration with blood alcohol levels as low as .027 per cent; performance in the absence of motion was not significantly impaired.[10] Such findings indicate the insidious nature of the effects of alcohol on performance. A pilot who drinks lightly may convince himself that his ground-level abilities are unimpaired and thus be convinced that it is safe to enter the cockpit. However, if while flying, particularly at night with dim display illumination, that pilot encounters vestibular stimulation as a result of maneuvers, turbulence, or an inner ear dysfunction, he may readily experience disorientation and blurring of vision. Control of his eye movements by visual fixation will have been reduced by the alcohol, and vestibular control will be free to take over the driving his eyes relative to the instruments. Such occurrences will increase the likelihood that the pilot will misread the instruments and react incorrectly. The results could well be fatal.

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DEMONSTRATION

During the time allocated for discussion following the formal presentation, Dr Collins demonstrated the portable rotating chair and goggles, illustrated in Fig. 6 of the paper. He enumerated the procedures employed for disorientation familiarization and several members of the audience tried out the device.

Dr Gilson also reported briefly recent work carried out at CAI and NAMRL on the effect of ethyl alcohol on vestibular function. In particular he showed how ethanol impaired the suppression of canal nystagmus which occurs when the subject attempts to fixate on a stationary visual target. In addition to EOG measures of nystagmus, the impairment of subject ability to see instruments and perform a simple tracking task when intoxicated and exposed to torsional oscillation was described.

THE DISORIENTATION ACCIDENT - PHILOSOPHY OF INSTRUMENT FLYING TRAINING

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SUMMARY

Patterns of disorientation occurrences in the United Kingdom RAF and Army for the period 1960-1970 are examined in order to formulate possible explanations and recommendations concerning, in particular, the philosophy of instrument flight training. The aircraft types most commonly involved and the circumstances confirm the liklihood of sensory incongruity being a contributory factor in the majority of cases. The underlying differences between 'primary' and 'secondary' disorientation are discussed; the latter term being used to describe the type which leads to an active state of confusion. The author suggests that the predominant emphasis both in aeromedical indoctrination and instrument flying practice is concerned with preventing primary spatial disorientation, but that insufficient effort is made towards ensuring that primary disorientation when it occurs, does not develop into the dangerous secondary stage. The various methods of simulation of instrument flying are examined in this light. Recommendations are made for increasing the amount of 'stress' during IF practice, by increasing the mental work load and adding distractions and diversions whilst carrying out the 'mechanical' tracking task of flying on instruments.

INTRODUCTION

Happily there has been a steady decrease in overall accident rates over the years. As aircraft performance increases however, major accidents are often difficult to explain with certainty. When investigators are unable to turn up obvious technical causes, the focus of attention is turned upon the aircrew involved and in particular, the pilot. Of the various human factors which can explain accidents and incidents, spatial disorientation is both an intriguing and important possibility.

Wing Commander Lofting from the RAF Directorate of Flight Safety has already reviewed the United Kingdom RAF and Army statistics on spatial disorientation in flight for the decade 1960-1970, (A2). In this paper I shall discuss possible explanations for the pattern of these occurrences and make certain recommendations for reducing the incidence of this hazardous condition. In particular I shall dwell upon the philosophy of instrument flight training and its relationship to spatial disorientation.

ACCIDENT PATTERNS

The four fixed wing aircraft which feature significantly in disorientation accidents are the Canberra, Hunter, Lightning and Jet Provost. These four types of aircraft have cockpit canopies which are either completely clear and frameless or have only a windscreen arch. One can readily visualise a situation where either at high altitude or in haze conditions at low altitude, the pilots sitting in these open 'bubbles' would have a minimal visual input whilst searching for a target, other aircraft or ground feature. These are conditions which permit vestibular or proprioceptive information to predominate leading to sensory incongruity when cross checks are made with the aircraft instrumentation. In this context it is also interesting to note that night flying and inexperience have been shown to be significant factors predisposing to aircraft disorientation accidents. I believe there is another important factor which is common to that group of aircraft namely that they are predominantly flown solo. This point is concerned with underlying psychological factors related to disorientation and will be discussed later. In the case of the Sioux helicopter which has both the canopy 'bubble effect' and a lack of adequate instrumentation at that time, the situation is aggravated still further and sensory incongruity could readily occur.

It has been shown that no accidents in the Royal Air Force during the period 1960-1970 were apparently caused by disorientation during the landing approach, (A2). I believe that one can account for this in two ways. Firstly, there has been considerable publicity given to the problem of cross reference between the aircraft instruments and the ground at this stage of the flight profile and I would like to think that the aviation medicine teaching has been effective in alerting pilots to this as a possible cause of disorientation. Secondly, at this stage of flight the pilot is predominantly 'locked-on' to his full instrument panel and the time spent looking out at the outside world is relatively short. I believe that this balance between the time spent in handling reliable information and that likely to provoke potential conflict is less likely to produce disorientation than the opposite situation in which the pilot is predominantly looking into a featureless outside world and only looking at his instruments occasionally.

AIRCRAFT INCIDENTS

It is interesting to note that of the 59 incidents attributed to disorientation, 23 of these apparently were associated with ear infection, physical indisposition or excessive head movements. Although one is

inclined to associate these situations with a marked increase in vestibular afferent signal flow I feel more inclined to ask why this signal flow caused the individual to be disturbed. I shall refer to this later when discussing the underlying factors predisposing individuals to disorientation which causes occurrences.

The proportion of inexperienced pilots in the incidents tabulated was considerably lower than in the case of accidents from this cause. It has been suggested that perhaps inexperienced pilots do not report these occurrences, (A2). This is certainly a possibility but I would like to suggest an additional explanation. This may be associated with the type or severity of the disorientation we are dealing with. In his excellent chapter on 'Spatial Disorientation in Flight' in the textbook of Aviation Physiology Dr Benson referred to primary and secondary disorientation, secondary disorientation being the type which leads to an active state of confusion. I suggest that perhaps the more experience the aviator, the more prone he is to secondary spatial disorientation because his experience has caused certain patterns to be 'set' in his mind and conflicting cues are more likely to cause sensory incongruity. In the case of the inexperienced student aviator, on the other hand, he has fewer such 'sets' and perhaps he is less prone to secondary spatial disorientation. The higher accident rate associated with disorientation in the inexperienced could be explained by the fact that when disorientation becomes marked, in such cases, whether it be primary or secondary, panic or not, the individuals lack of experience means that he is less able to cope with the difficult aircraft handling which is necessary to prevent an accident.

FACTORS PREDISPOSING TO DISORIENTATION

I have already referred to primary disorientation which is a situation in which the aviator is unaware that his perception of altitude or position is incorrect and it is only when he checks or compares the orientation perceived by one sensory channel with that from another that he is likely to realise that his original perception of aircraft attitude was incorrect, (Benson). This can then be followed by a state of confusion or uncertainty which has been called sensory spatial disorientation. Gillingham in his excellent 'Primer of Vestibular Function, Spatial Disorientation and Motion Sickness' refers to the lack of sensory congruity as determined by previous experience as an important factor in the production of motion sickness and the same can be said for disorientation. Although it is true that aircraft performance is increasing pretty rapidly these days, the occurrences which have occurred in the United Kingdom are not always associated with particularly dramatic aircraft manoeuvres. My own experience with cupulometry whilst studying motion sickness, leads me to believe that although the end-organ response apparently varies greatly from individual to individual this is due to the way in which the individual handles this signal flow from the vestibular apparatus, rather than any difference in the end-organ itself. Vestibular stimulus is no doubt the 'seed' but it is the state of the 'soil' namely the individual himself, his personality, his state of training and his insight into the problem which causes this hazardous secondary spatial disorientation.

Perhaps then the ear infections and physical indispositions that were noted in various incidents in the Royal Air Force statistics so adversely affected the individual that he was unable to cope with stress whether it be vestibular in origin or from any other source, for that matter.

I referred earlier to the possible significance of the solo situation. In extreme cases, where aircrew are suffering from some phobic state they frequently emphasise that the problem is much worse when flying solo. Even a passenger who has no knowledge of flying whatsoever can enable a phobic pilot to cope with his problem and aircraft in many instances. Perhaps then the solo state is the 'straw which breaks the camel's back' and prevents the pilot handling his secondary spatial disorientation. Is there a very narrow line between what we call 'secondary spatial disorientation' and a 'phobic' state?

PREVENTION OF DISORIENTATION

You are all very familiar with the many useful steps which have been taken in recent years to reduce the incidence of disorientation. Aeromedical indoctrination has I am sure been very effective in bringing this matter out into the open and that in itself is a big step forward. I am sure that treating the problem as a 'normal' occurrence has given reassurance and a sense of understanding to many aircrew who might have got into trouble. Nevertheless I believe that we can do more in a practical way particularly in our airborne exercises. It is in this area that I should like to dwell for a few moments by saying something about the philosophy underlying instrument flying practice, as I see it.

PHILOSOPHY OF INSTRUMENT FLYING TRAINING

Great stress has been placed upon the need for an individual pilot to be able to fly instruments well; similarly methods of instrument scanning have been improved and taught very effectively to students and experienced aircrew. This is excellent and very necessary, but I believe that we have perhaps erred by placing insufficient emphasis on dealing with the stress which is associated with instrument flying.

Airborne spatial disorientation training has tended to demonstrate the need for instruments and the unreliability of 'seat of the pants' sensations. It has also stressed the need for the student to believe his instruments when disorientated. These are useful exercises but in my view, again fail to 'stress' the student sufficiently in the training situation.

Perhaps I can best make my point about instrument flying simulation in flight by examining the significant constituents of actual instrument flying and its associated problems from the point of view of the pilot. These are not necessarily in their order of priority.

a. The pilot must be able to perform a tracking task accurately and smoothly with minimum lag time;

b. He must be able to suppress misleading vestibular and/or visual information when it conflicts with his instrument presentation;

c. He must be confident in himself and his ability to cope with a high performance aircraft in a difficult instrument situation.

As far as performing a tracking task is concerned, this is a mixture of natural ability and good flying training. I suggest that graduate pilots do not lose control of their aircraft for this reason alone. I believe that the standard of training in the NATO air forces is high and such an aviator would have been eliminated as being well below the required standard. The second point deals with sensory incongruity in the real IF situation. When looking out of the cockpit into a hazy featureless sky, the visual input is minimal as I said earlier and this can have two effects:

i. The misleading or inaccurate vestibular or 'seat of the pants' information can become dominant:

ii. On returning to look at the instrument presentation, the picture may now be at variance with existing false perception from misleading sources.

Concerning the third point, the pilot's state of confidence, this denotes good practice and the ability to cope with stressful situations from whatever cause.

I would suggest that IF simulation as it is commonly practised does not meet all these requirements;

a. Simulated instrument flying under the hood removes all sensory conflict, or nearly all, since the pilot cannot look out and he therefore gets a maximal input of reliable vi[illegible]l information from his instrumentation. There is some stress, but this is minimised by the presence of the instructor and no other stress is built in. On this point I was interested to read in a recent Board of Inquiry the comments of a very senior Royal Air Force officer who wrote: 'dual will never lack the psychological security of a qualified pilot at the students elbow.' Having read that I wondered if I was preaching to the converted!

b. When a visor is used instead of a hood the comments are similar, but in addition, the trainee knows that if the going is really tough a small head movement will give him a picture of the outside world. Even if he does not use this facility, nevertheless the possibility 'detensifies' the simulation.

If one accepts these premises then a logical approach to simulated flying practice can be proposed:

a. Increase the 'stress' during practice and get away from a simple tracking task by emphasising pilot interpreted aids so that the individual is made to think 'three-dimensionally' when on instruments. He must be distracted from merely 'following his needles', by having to think about other problems such as navigation or aid interpretation, to a far greater extent.

b. He must somehow be made to look out and 'suffer', if that is the right word, the problem of diminished visual input leading to conflict. This is perhaps difficult to simulate but by no means impossible. I recall during World War 2 that one had to fly a number of so called 'day-night' sorties before going night flying. We students used to reckon that you should have night flying experience before doing day-night practice because it seemed more stressful! This consisted of wearing very dark amber goggles and flying on sodium illuminated instruments. The students could see nothing of the outside world except three or four isolated sodium lights on the ground at the end of a controlled approach and he had to carry out a landing using these as his flare-path. Although finals have not been associated with many accidents this would certainly be one way of forcing an individual to lookout of the cockpit and experience sensory incongruity at the end of his instrument approach. Various other schemes, such as 2 stage contra-amber and 2 stage contra-blue have been used. These were a mixture of blue goggles with an amber screen on the reverse. These systems tended to be cumbersome but technology has improved so much that the shortcomings of the old systems could be overcome now.

I should also like to see a student be given as much actual instrument flying as possible in his training programme. There is no finer way to turn out a fully competent pilot who can fly his aircraft to its limits. To that end it is important that the dual-solo ratio is watched most carefully so that there must be a minimum of solo sorties before a student is permitted to go night flying. Without doubt no student should be permitted to fly solo at night until he has at least 25 hours day solo on type and has achieved a satisfactory level of instrument training.

CONCLUSION

The philosophy I have tried to preach is that it is not sufficient for the student to be able to cope on instruments. Dangerous secondary spatial disorientation represents a situation where a distracting vestibular input has pushed a pilot over the point of balance of ability. He should be trained in such a way that he can carry out a number of tasks as well as flying on instruments accurately and well; it is only be being so trained that he will be able to sit back and 'enjoy' his instrument flying. It is not sufficient to explain this to him during the lecture period he must be so trained and sufficiently 'stressed' during instrument training that a balance is achieved which ensures that he will achieve a state of confidence in his ability to fly all-weather missions naturally. This means that whenever he is confronted with some curious visual illusion; or when he loses his leader in formation in cloud; or is asked to change a radio frequency at a critical time; or his bladder is full; or he is short of fuel; none of these things will be so much to the fore at conscious level that he will be unable to suppress them and be unable to cope with a complex tracking task in the form of an instrument flight procedure.

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DISCUSSION

SCAND. This is only a practical question. Did you find any special correlation between the incidence of disorientation and fatigue or lack of sleep?

DOBIE. The investigation of any possible case of disorientation is always fraught with difficulties and I cannot demonstrate any specific correlation between sleep deprivation or fatigue and disorientation. Nevertheless, in relation to the views which I have presented in this paper I would expect that these would be typical of many 'personal factors' which can contribute to disorientation.

LOFTING. You expressed your belief in the need for further instrument flying training techniques, which accords very much with the DFS view from a study of air accidents. Do you consider that these new techniques must be done in the air, that is, an artifically loaded real-flying situation? Or do you see ground simulation in sophisticated visual-and-motion trainers as a field for the new techniques which we need to arm our pilots against the killer situations of disorientation?

DOBIE. I believe that whatever ground orientation demonstration devices are used, ultimately the programme must be taken in to the air. This orientation training in flight would consist of a form of instrument flying practice designed to 'load' the pilot progressively to the maximum with a variety of inputs. Ideally, flying on instruments should be as 'natural' to the trained pilot as flying contact (VMC).

CLINICAL EVALUATION AND TREATMENT OF DISORIENTATION IN AIRCREW

Air Commodore P. J. O'Connor

SUMMARY: A special panel exists in Great Britain for evaluating disorientation in aircrew. 90 cases were seen in the period 1960 to 1971. Most of the patients were military aircrew; test pilots and helicopter pilots were more common than expected. Disorientation was common in the third and fourth decades. Presenting symptoms were divided into:

1. Increased sensory input.
2. Decreased sensory input.
3. Disturbed central thought processes.

Treatment was by explanation and reassurance with the addition of rehabilitation flying and treatment of any associated psychiatric disorders. 60% returned to full flying.

This paper deals with 90 aviators complaining of disorientation in the air in the period 1960 to 1971.

In Great Britain we have a panel for dealing with cases of disorientation in the air of such severity that they merit specialist investigation. This panel consists of an Ear, Nose and Throat Consultant, a Physiologist who is an international authority on disorientation and myself, a Neuropsychiatrist. All cases of disorientation, whether in military flying or civil, which are thought to require expert guidance, are referred to this panel.

One tenth of the patients were civilian and of this number three were test pilots. The low incidence of disorientation in civil aircrew probably reflect the fact that the military aviator and the test pilot fly their aircraft to the limit of its capability. In civil flying the emphasis is at all times upon smooth flying and the avoidance of any manoeuvre which might cause passengers alarm. Because the military pilot has to fly the aircraft to the limits of its capability and has to be trained in such precision flying as is required in low level attack and formation flying, any symptom which undermines his confidence in his ability to control his aircraft assumes much greater importance. It is for these reasons that we see far more military aviators and test pilots than civil aircrew at the disorientation panel

One tenth of the disorientation patients had developed their symptoms in helicopters. This is a higher incidence in helicopter pilots than was expected as helicopter pilots do not make up one tenth of the total strength of aircrew in this country. I believe that disorientation is disproportionately common in helicopter flying because this aircraft demands far more control to keep it in the air than a fixed wing aircraft which can be flown by the automatic pilot if the captain is temporarily indisposed.

90% of the disorientation referrals were pilots. Clearly disorientation is more important to a pilot than to a navigator as far as the safety of the aircraft is concerned. Figure I shows the age of the aviator at the time he was referred to the panel.

Fig. I – Age at onset of disorientation

Age Group	<20 years	20-29	30-39	>40
% of disorientation cases in this group	5	42	42	11

I was surprised to find the high incidence of disorientation in the third and fourth decades.

The presenting symptoms may be classified in relation to the psychophysiology of disorientation. The brain needs to know continuously the attitude of the body. This knowledge is computed from information from the eyes, the labyrinth, the muscle stretch receptors and in the case of the aviator from the instrument panel of the aircraft. The cues from these sources are computed to give an updated model of the body's position in space. This orienting mechanism may be upset in a number of ways. The way in which the mechanism is disturbed dictates the form the disorientation will take.

1. Increased signal strength in one channel may upset the computing mechanism; Coriolis stimulus, pressure vertigo, distracting stimuli such as car headlights travelling at right angles to the runway or the sudden falling away of the terrain on flying over a cliff edge; faulty flying manoeuvres such as stalling at the top of a loop.

2. Reduction of sensory input; sudden change from VMC to IMC especially on unexpectedly entering a cloud at night; the break-off phenomenon at altitude when the horizon has fallen below the comfortable level of vision; completely calm sea without ripples; at about 5000 feet it is no longer possible to pick up the detail of vegetation and some aviators feel disorientated at this stage.

3. Heightened arousal may interfere with central thought processes in a number of ways; the span of attention may be narrowed, usually due to anxiety, and this may cause coning down of vision onto one instrument instead of scanning the essential dials. In target fixation the pilot tends to fly into the target he is attacking instead of breaking off in good time. The toxic effect of an alcoholic hangover seem to lower the threshold for becoming disorientated. Anxiety states and hyperventilation have similar effects. Input overload may occur when a great number of cues have to be attended to at the same time as in formation flying or low level attacks at night in single seat aircraft. The tension engendered by the presence of an examiner during instrument ratings increases the tendency to disorientation. Unexpected visual effects as on looking through a window in the floor of an aircraft. Hypochondriacal fear that any altered bodily sensation may be a prelude to losing consciousness often gives rise to disorientation. Illusions of position (the leans) and the more striking illusion that the aircraft is upside down are related in part to the sensory deprivation. A less common form of disorientation is the inability to appreciate subjectively the motion of the aircraft with the resulting belief that the plane is stationary or that it has not turned after banking.

Treatment of disorientation must be by reassurance and rehabilitation. If the disorientation has been of recent onset and can be explained to the pilot in terms which he understands, this may be all that is required. Sometimes the explanation must be coupled with rehabilitatory flying especially if this can be supervised by a doctor who is himself a pilot. If the pilot has worried about his disorientation for some time before seeking advice and if he is predisposed to neurosis, the disorientation may lead into a phobic fear of flying which requires prolonged treatment. If the aviator is severely predisposed to neurosis or if the disorientation has spread to other methods of travel such as trains or cars the prognosis is worse. In our experience 60% return to full flying, 7% to restricted flying while 33% were grounded.

DISCUSSION

JONES. You said you were able to recover two thirds of the pilots who came under medical care because of disorientation. What was the disposition of the other third? Were any of these officers in their non-flying career allowed to command or control aviators?

O'CONNOR. Of the aircrew with disorientation whom I have seen, 60% returned to normal flying duties, 7% went back to restricted flying and 33% were grounded. The third who were grounded were probably quite fit for most ground duties, but it is an executive decision that aircrew who are grounded for neuropsychiatric causes are generally discharged from the Service. They are not employed as Air Traffic Controllers.

TECHNICAL EVALUATION

The Disorientation Incident was the theme of the first part of the 28th Meeting of the AGARD Aerospace Medical Panel held in Luchon, France, on 28-30 September, 1971. In his introductory remarks Dr Benson explained that the objective of the Aerospace Medical Panel in choosing Spatial Disorientation as a special topic for this meeting was to determine the operational significance of this perceptual disturbance in the flight environment. He suggested that it was widely recognised that all aircrew suffered from disorientation at sometime or other, but little up to date information was available about the incidence of disorientation or how frequently it was the prime or contributory cause of aircraft accidents. Apart from information about the operational consequences of disorientation, it was important that the underlying mechanism of the condition should be understood in order to provide a scientific basis for the development of techniques and training procedures which would reduce the incidence of spatial disorientation in flight.

During the course of the meeting which occupied two half-day sessions sixteen papers were presented. Full texts of all the papers were available in AGARD Conference Preprint No 95, so the speakers were able to spend the time available in the explanation of essential findings. This technique appeared to work well and allowed adequate time for discussion after each presentation. The papers presented could be broadly classified under four main headings: a. Description and analysis of incidents reported by aircrew. b. Analysis of accidents attributable to disorientation. c. Laboratory studies. d. Training procedures.

Disorientation Incidents

Although spatial disorientation has been recognised, and to a large extent understood, for many years it was apparent both from formal presentations and ensuing discussion that aircrew continued to experience illusory perceptions of aircraft orientation.

The findings of two recent questionnaire studies were reported; one carried out on 2,000 US Navy pilots and the other on 336 US Military pilots. The experience of disorientation of one type or another during flight was almost universal (93-97%), yet only 11% of the pilots reported that they had disorientation 'frequently'. Nevertheless 38% considered that their safety in flight had been hazarded by a disorientation incident. The frequency with which the different types of incidents were noted was similar to that found in a comparable survey carried out in 1956. The most commonly reported type of disorientation was a false perception of the attitude or motion of the aircraft, disorientation due to the misinterpretation of visual information was less frequent although 92% of pilots flying alone in jet aircraft reported confusion of stars with surface lights.

In general, however, aircraft type and operational role did not appear to influence the frequency with which the different types of disorientated were reported. Notably, helicopter pilots reported the same sort of incidents as pilots of fixed wing aircraft. Among these, mention should be made of the dissociative sensations characterised by the 'break-off phenomenon' which, as several speakers pointed out, is not restricted to pilots of single seat, fixed wing aircraft flying at high altitude, but can occur in helicopters when flying as low as 500 ft.

In addition to the 'break-off' phenomenon several specific types of disorientation were discussed in some detail. The illusory sensation of a pitch-up change in attitude, brought about by the changing force environment associated with catapult launch or turbulence penetration (Jet upset), is of special importance as accidents have been directly attributable to the pilot pushing the control column forward to correct for the apparent change in aircraft attitude. The special problems of vertigo induced by a change in pressure (alternobaric or pressure vertigo) were also discussed, though symptoms of this type were only reported by about 10% of the aircrew population.

From formal presentation and discussion it was apparent that a considerable amount of information was available about the different types of spatial disorientation and the frequency such incidents are reported. Knowledge about how frequently aviators become disorientated is less certain, though a qualitative assessment of the incidence of disorientation was provided by the US Navy questionnaire. Yet more important is the frequency with which disorientation jeopardises flight safety. Over a third of the pilots had experienced an incident which they regarded as a hazard either to themselves or to the aircraft, but little is known about the frequency of occurrence of these incidents. Yet potentially far more dangerous are those situations in which the pilot is not aware that his perception of aircraft orientation is incorrect. Such incidents are, as one speaker remarked, the 'real killer' and not amenable to anamnestic study.

Analysis of Accident Statistics

Four papers were presented which dealt with aircraft accidents in which spatial disorientation was considered to be a causal factor. In analysing the chain of events which leads to an aircraft accident spatial disorientation poses special problems, for the investigator is rarely provided with unambiguous evidence that the error in the pilot's control of the aircraft was directly attributable to an error in his perception of the motion and attitude of the aircraft. More commonly the conclusion that an accident was caused by spatial disorientation must be obtained by inference, which itself is likely to be influenced by the attitude, experience and judgement of the investigators. This feature was illustrated by UK (RAF and Army) accident statistics which showed a higher incidence of accidents attributable to disorientation in the period 1966-1970 than during the previous quinquennium, when the problem of disorientation was less publicized in the Service. It was suggested that the figures for the period 1966-1970 were a more accurate measure of the disorientation accident rate. Over this period the rate was 3.7% of all accidents or approximately 11% of aircrew error accidents. Analysis of US Army accident statistics for 1966-1967 indicated the 7.1% of all accidents could be classified as 'orientation error' which represented 10.3% of the pilot error accidents. US Navy statistics showed that 6.8% of all accidents in 1969 were coded for disorientation/vertigo, although on detailed examination of the accident reports only 1% of the accidents could be definitely attributed to spatial disorientation.

Aircraft accidents, in particular those due to pilot error, rarely have a single cause. Indeed, only in 4% of all US Navy accidents coded for disorientation in 1969 and 1970 was this perceptual disability considered to be the sole cause of the accident. In the remainder, other psychological or environmental factors were coded along with disorientation in the accident report. Of these contributory factors, restriction of visibility by weather, haze or darkness was the most frequently reported. The association of disorientation with instrument flight, and in particular the transfer from external visual reference to instrument reference was clearly demonstrated by UK and US accident data as well as by the incident questionnaires referred to in the previous section.

US Naval accident statistics also showed that the frequency of orientation error accidents were proportionately higher during the first two years of flying than during subsequent phases of the aviators career. The experienced aviator is not immune from spatial disorientation, but it would appear that he is less likely to allow his control of the aircraft to be disturbed by the illusory sensations which characterise spatial disorientation.

Laboratory Studies of Certain Aspects of Disorientation

The environmental, physiological and psychological factors concerned in the aetiology of spatial disorientation are numerous, so it was understandable that in a short meeting the detailed analysis of specific types of disorientation would not be comprehensive.

A notable contribution to the understanding of the illusory perception of a pitch up change in attitude which can occur during catapult launch was provided by the results of experiments in which subjects were exposed to a simulated launch profile in the NADC centrifuge. It was found that an X-axis acceleration

pulse of approximately 4g acting for 3 sec led to an illusory perception in pitch attitude which persisted for up to 60 sec after the stimulus. This illustration of the change in perception of attitude, brought about by a transient X axis acceleration complemented the established data for long duration low amplitude accelerations and emphasised the importance of the use of flight instruments if aircraft attitude is to be correctly perceived in a changing force environment.

Transient changes in the force environment were also used in a simulated flying situation in an attempt to induce the perceptual and motor disturbances of what has been called the 'Giant Hand Phenomenon'. Strictly this is not spatial disorientation, but rather an involuntary movement of the pilots limbs in which he feels as if the control column is being pulled away from him as if by a 'giant hand'. The condition is apparently not common, but three incidents were described, which included one ejection.

The effects of ethyl alcohol on vestibular function were discussed, and the inability of intoxicated subjects to suppress nystagmus induced by rotational stimulus was clearly demonstrated in a ciné-film. Results of other experiments were also reported which provided quantitative evidence of the failure of suppressive mechanism and of the decrement in visual performance in subjects who had been given alcohol. These findings emphasized the dangers of flying after drinking and illustrated that in addition to the impairment of cerebral function engendered by alcohol, it also degrades the aviator's ability to see instruments when exposed to potentially disorientating motion.

Selection and Training

The psychological functions influencing an individual's reaction to motion stimuli and the adaptation which occurs when exposed to a novel motion environment were reviewed in detail. This work provided a theoretical framework for training procedures and selection tests relevant to the problem of spatial disorientation in flight. The Brief Vestibular Disorientation Test has been found to be a valid predictor of failure in flying training, but has not been related to an individuals susceptibility to impairment of control by disorientating sensations or specifically to an orientation error accident. However, it was considered that with further development the test would have a predictive capability in assessment of an individuals susceptibility to in-flight disorientation.

There was general agreement with the opinions of several speakers who considered that orientation error accidents would be decreased if training, both on the ground and in the air were improved. Apart from lectures, which inform aircrew about the various forms of disorientation and the conditions of flight in which they occur, the benefits of various techniques for 'disorientation familiarization' were discussed. A simple, portable, rotating chair was demonstrated and the manner described in which it was used to produce sensory and visual illusions comparable to those experienced in the flight environment. The range of illusions which can be demonstrated is enhanced by the use of eccentric rotation (eg a centrifuge), but if such a device is used for training as a dynamic flight simulation rather than for a simple demonstration of disorientating sensations it was suggested that there could be an undesirable transfer from simulated to actual flight.

While the ground based demonstration of disorientation is a useful contribution to the training of aircrew, it was agreed that a high degree of proficiency at instrument flying was the aviator's best protection against the impairment and possible loss of control engendered by conflicting and distracting sensations. Apart from the demonstration of disorientation in the flight environment it was argued that it was not sufficient for the student pilot just to be able to fly by instruments; he should be trained to use instruments under 'stressful' conditions so that he developed the confidence to fly all weather missions and the ability to deal with critical in-flight incidents without disorganization of aircraft control. The high incidence of disorientation which occurs on transition from external visual reference to instruments implies that greater emphasis should be placed on this aspect of the flying task during training.

RECOMMENDATIONS

1. Training

The importance of ground and flight training in reducing the incidence of spatial disorientation and orientation error accidents was emphasised by many participants. Accordingly it was decided to form an Ad Hoc Working Group which would prepare an advisory report on orientation training. The Working Group would review training procedures and make recommendations on a. topics to be covered in ground school lectures, b. the use of disorientation familiarization devices and disorientation trainers, c. the natures of in-flight training and in particular instrument flight training procedures and d. the maintenance of instrument flying skill and refresher training.

2. Instrument displays

Other methods of reducing orientation-error accidents were suggested:

a. Instrument displays should be developed which allow aircraft orientation to be determined more rapidly and more certainly than with the existing cockpit instruments. The objective should be to provide flight instruments which have the 'force' of information available during contact (VMC) flight.

b. The potential benefits of the head-up display in aiding VMC-IMC (VFR-IFR) transition and the possible amelioration of disorientation during this critical phase of flight should be evaluated.

c. Helicopters should be provided with instrumentation appropriate to this type of flight vehicle, with adequate indication of translational motion and ground clearance.

A J BENSON

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